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SYNTECTONIC DEPOSITION OF LOWER TO MIDDLE SILURIAN SANDSTONES, CENTRAL SHENANDOAH VALLEY, VIRGINIA

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The stratigraphy of the Upper Ordovician to Middle Silurian rocks of the Massanutten synclinorium in the Shenandoah Valley of Virginia contrasts sharply with the stratigraphy in the folded part of the Valley and Ridge province to the west (Figure 1). Five formations between the top of the Martinsburg Formation (Middle and Upper Ordovician) and the top of the Keefer Sandstone (Middle Silurian) crop out in the Cove Mountain outcrop belt to the west of the Shenandoah Valley, whereas the Massanutten Sandstone represents the same time span in Massanutten Mountain (Figure 2).

Only two of the formations that are exposed west of the Shenandoah Valley, the Tuscarora Formation and the Keefer Sandstone, contain quartz arenite in the same abundance as that found in the Massanutten Sandstone. Although the Tuscarora, Rose Hill, and Keefer are correlated with the Massanutten (Young and Rader, 1974; Figure 2), they comprise together a maximum of 330 feet (101 m) of thickness, whereas the Massanutten is 650 feet (198 m) thick near New Market Gap and about 1,200 feet (366 m) thick at the northern end of the outcrop belt (Rader and Biggs, 1976).

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It is proposed that the differences in thickness between the quartz arenite formations to the west of the Shenandoah Valley and the Massanutten Sandstone are, at least partially, a result of deformation penecontemporaneously with deposition during the Taconic orogeny. Downfolding may have begun in the Massanutten synclinorium area while an arch may have been forming to the west (Figure 2) (Rader and Perry, 1976). Assuming such a pattern of deformation, the thickness of the quartz sand deposits should be greater in the synclinal trough than over the arch. The direction of current flow should also have been influenced by the tectonics. Currents would probably flow down the axis of a synclinal trough whereas they would flow away from the crest of an arch. The crest of the Shenandoah axis was probably slightly positive—above sea level or shoaling (personal communication, E. K. Rader, 1977).

To test the validity of this hypothesis, six stratigraphic sections were described and measured in Rockingham County, Virginia and one each in nearby Page County, Virginia and Hardy County, West Virginia (Figure 1). During the description and measurement of the sections in Massanutten Mountain the dip directions of cross-strata were measured in the quartz arenite beds using the technique described by Yeakel (1962, p. 1517). Paleocurrent rose diagrams were constructed after correction of cross-strata directions for tectonic tilt (Potter and

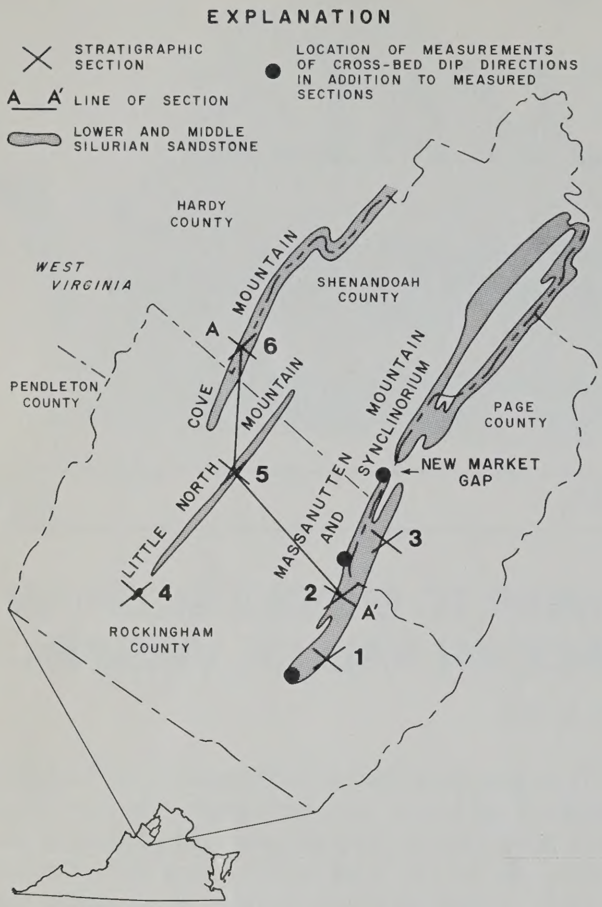

Figure 1. Index map of area being discussed.

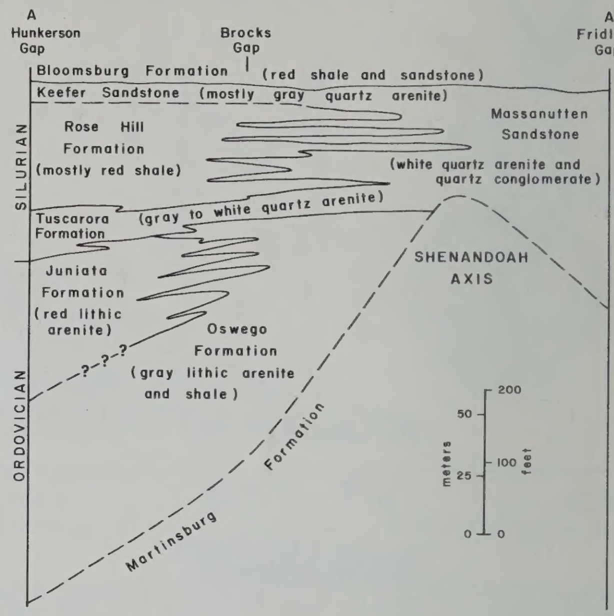

Figure 2. Stratigraphic relationships and lithology of Upper Ordovician to Middle Silurian formations in Rockingham, Page, and Shenandoah counties, Virginia (modified after Young and Rader, 1974; Rader and Perry, 1976a). See Figure 1 for line of section A-A'.

Pettijohn, 1963, p. 260). Cross-strata dip directions were also measured at three other localities on Massanutten Mountain (Figure 1), for a total of 142 separate measurements. The cross-strata measurements made on Massanutten Mountain south of New Market Gap (Figure 1) are, so far as is known, the first measurements of their kind made in that area. These data were compared to those collected by Yeakel (1962) in Massanutten Mountain north of New Market Gap and in Little North Mountain.

The authors wish to thank E. K. Rader and W. J. Perry, Jr. for their many valuable suggestions regarding field aspects of this study and E. K. Rader for his critical reading of the manuscript and suggestions for its improvement.

STRATIGRAPHY

The stratigraphy and lithologic characteristics of the Massanutten Sandstone, Tuscarora Formation, Rose Hill Formation, and Keefer Sandstone have been studied by several geologists and are well-documented (Butts and Edmundson, 1939; Butts, 1940-41; Woodward, 1951, 1955; Brent, 1960; Allen, 1967; Young and Rader, 1974; Rader and Perry, 1976a, 1976b; and Rader and Biggs, 1976).

The stratigraphic interpretation of the Upper Ordovician to Middle Silurian section at Brocks Gap (Figure 2, Table 1) here advocated is basically that of Woodward (1955) as reinterpreted by Rader and Perry (1976a, 1976b). Accordingly, the upper 75-100 feet of the "Lower Silurian and Upper Ordovician sandstone" unit (Rader and Perry, 1976a, Table 1, p. 38) is considered to be equivalent to the Tuscarora Formation rather than the Oswego Formation of Brent (1960), and the Clinch (Tuscarora) Sandstone of Brent (1960) is considered to be the Keefer Sandstone (Figure 2).

PALEOCURRENTS

The predominant paleocurrent direction in the Upper Ordovician to Middle Silurian rocks of the central Appalachians is to the northwest (Figure 3; Yeakel, 1962). In Massanutten Mountain north of New Market Gap, however, Yeakel (1962) found the primary modes of most paleocurrent roses to be northeasterly (Figure 3). Measurements made by the writers at locations south of New Market G (Figures 1, 3) show paleocurrent modes sim those north of the gap. In this southern area four

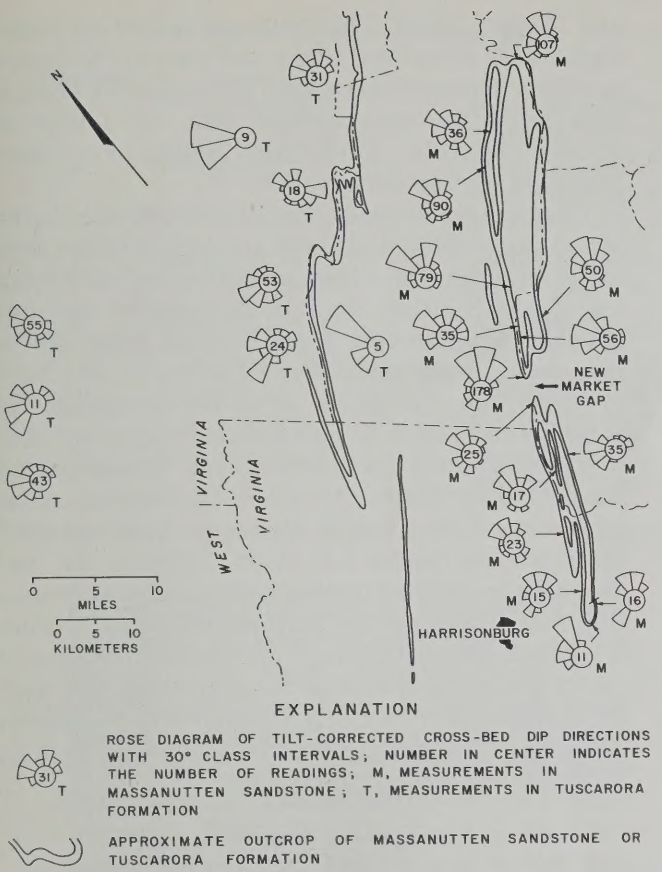

Figure 3. Rose diagrams of cross-bedding dip azimuths in the Massanutten Sandstone and Tuscarora Formation, central Shenandoah Valley, Virginia. Measurements south of New Market Gap in Massanutten Mountain were made by the writers, all others are from Yeakel (1962, Plate 3).

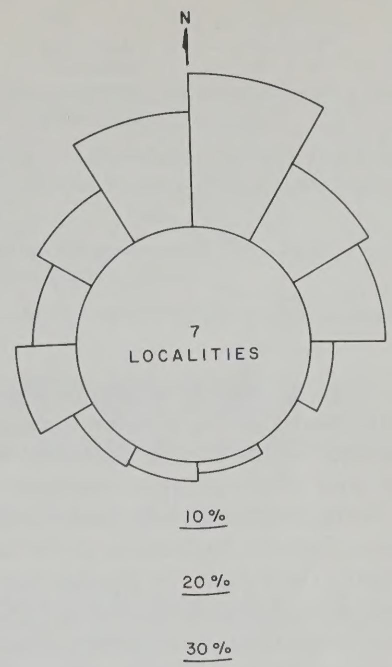

Figure 4. Composite current rose of seven equally weighted localities; measurement of 142 cross-beds in the Massanutten Sandstone south of New Market Gap.

current roses have primary modes to the northeast, one to the north, and one to the northwest. Figure 4 summarizes the paleocurrent directions in the southern part of Massanutten Mountain where a predominant northeasterly mode 60 degrees east of the regional trend, is parallel to the structural axis of the Massanutten synclinorium.

The northeasterly trend of paleocurrent directions in Massanutten Mountain contrasts markedly with the prominent northwesterly mode in most of the central Appalachians. The exposures in Little North Mountain show a scattering of paleocurrent directions that also are somewhat different from the regional trend. Not enough cross beds were exposed, however, for collection of sufficient data to allow construction of a current rose.

GEOLOGIC HISTORY

The paleocurrent data suggest that during Early Silurian time the Massanutten Mountain area was a northeastward-trending linear depocenter, probably due to the initiation in that area of synclinal folding. A few miles to the west, the adjoining anticline was beginning to form. It is apparent from the current roses (Figures 3, 4) that these folds were superimposed on the regional northwest paleoslope existing during the Taconic orogeny. Thus, many, though not all, streams carrying sand and gravel during Early Silurian time were diverted to the northeast down the incipient trough of the Massanutten synclinorium (Figure 5). The streams flowing toward the northwest were probably influenced by the arch forming to the west of the syncline, which may account for the scattering effect seen in the current roses for the Little North Mountain area. Farther to the west, the regional northwest paleoslope does not seem to have been affected by folding during this time interval (Figure 3).

The lower Massanutten Sandstone and the equivalent Tuscarora Formation to the west were forming during part of the regression caused by the Taconic orogeny to the east. The reddish sandy shale and fine sandstone (Rose Hill Formation) with marine fauna (Young and Rader, 1974, p. 23) that were formed in the Cove Mountain and Little North Mountain areas during early Middle Silurian time (Figure 2) show a marine transgression to within a

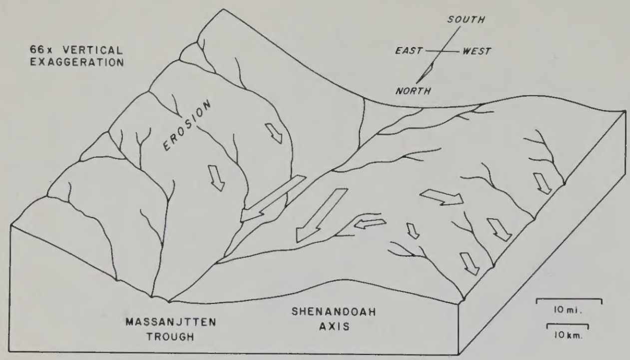

Figure 5. Paleogeography of the central Shenandoah Valley, Rockingham County, Virginia during Silurian time. The location of the Shenandoah axis may have been in the area of the present Mayland anticline (Rader and Perry, 1976a, p. 44). Sediments eroded from the rising Taconic Mountains to the southeast and to a lesser extent from the Shenandoah axis to the northwest were being transported in the direction of the arrows (measured paleocurrent directions) to the Massanutten trough, the depocenter, where they were also transported northeastward along the axis of the incipient Massanutten synclinorium.

few miles of the Massanutten synclinorium. Following this transgression, sand once again spread toward the northwest depositing the upper Massanutten and Keefer sandstones. The greater thickness of the Massanutten Sandstone and its higher proportion of conglomerate and coarse sandstone than in the Tuscarora and Keefer formations are also suggestive of the presence of a linear depocenter in the present Massanutten synclinorium area during Early and Middle Silurian time, while thinner deposits of quartz sand were being deposited over the arch to the west. The conglomerate and coarse sandstone of the Massanutten Sandstone are interpreted as point-bar and fluvial-channel deposits, whereas the finer sands of the Tuscarora and Keefer formations to the west are considered to be beaches, bar, or other tidal deposits (Rader and Perry, 1976b).

From the abovementioned data and reasoning it is concluded that deposition and deformation were occurring penecontemporaneously in the study area during Early to Middle Silurian time. Such syntectonic deposition has been demonstrated to have occurred in Virginia in the early stages of the Taconic orogeny, during or shortly after the deposition of Middle Ordovician limestones. For example, the Knox unconformity is found only on anticlines in Rockingham County and soft sediment slump structures exist in the Middle Ordovician Edinburg Formation near Harrisonburg (Lowry and Cooper, 1970). Thickness variations are associated with structural highs and lows in the Salem synclinorium near Roanoke (Tillman, 1976). Thus, it does not seem unreasonable that the Lower to Middle Silurian sandstones could have been deposited during deformation.

The distance between the linear depocenter in the Massanutten Mountain area and the incipient arch to the west may have been several miles less during the Early Silurian than is the present distance between Massanutten Mountain and Little North Mountain. Rader and Perry (1976a, p. 41) have proposed, on the basis of a reinvestigation of outcrops and new drill-hole data at Brocks Gap, that this part of Little North Mountain is "a transported slice of Upper Ordovician to Middle Devonian rocks within the Little North Mountain fault system." They propose (Rader and Perry, 1976a, p. 44) that the root zone of the inferred tectonic slice at Brocks Gap may underline the Mayland anticline, 7 miles (11 km) to the southeast. If this reinterpretation of the structural evolution of this area is correct, then the incipient arch in Early Silurian time postulated in this paper may have been only 5 to 6 miles (8 to 10 km) to the west of the trough.

SUMMARY OF CONCLUSIONS

(1) The thickness of Lower to Middle Silurian sandstones decreases from a maximum of 650 feet (198 m) on Massanutten Mountain south of New Market Gap to approximately 175 feet (53 m) at Brocks Gap on Little North Mountain approximately 13 miles (21 km) to the northwest of Massanutten Mountain.

(2) During Early Silurian time the direction of paleocurrents were predominantly to the north-northeast in the Massanutten Mountain area, both to the north and to the south of New Market Gap, although secondary paleocurrent rose modes to the northwest, southwest, and southeast have been measured. During the same time interval in the Little North Mountain area, paleocurrents appear to have been somewhat scattered, with current rose modes to the northwest, west, north, northeast, and southeast. The predominant paleocurrent directions in Lower Silurian sandstones in the remainder of the central Appalachians are to the northwest.

(3) A comparison of the thickness and paleocurrent directions of the Massanutten Sandstone with those of the Tuscarora and Keefer formations on Little North Mountain suggests that the Massanutten Mountain area was a northeastward-trending linear depocenter

Table 1. — Locations of stratigraphic sections.[1]

Number	Name	Location
1	Harshberger Gap	Along Massanutten Drive on First Mountain approximately 0.9 mile (1.4 km) northwest of intersection with State Road 647, Rockingham County, VA.
2	Fridley Gap	Along abandoned U. S. Forest Service road parallel to Mountain Run on Fourth Mountain approximately 1.5 miles (2.4 km) east of intersection of State Roads 722 and 620, Rockingham County, VA.
3	Cub Run Road	Along Cub Run Road on First Mountain approximately 1.7 miles (2.7 km) west of intersection with U. S. Highway 340, Page County, VA.
4	Cooper Mountain	Along State Road 732 approximately 0.5 mile (0.8 km) south of State Road 331, Cooper Mountain, Rockingham County, VA.
5	Brocks Gap	Along State Road 259 across from store at Brocks Gap in Little North Mountain, approximately 4.5 miles (7.2 km) west of Broadway, Rockingham County, VA.
6	Hunkerson Gap	Along Capon Run, Cove Mountain, approximately 0.5 mile (0.8 km) east of State Road 259, Hardy County, WVA.

[1] Descriptions of stratigraphic sections are on file at the Virginia Division of Mineral Resources, Charlottesville, VA.

during Early Silurian time, while an arch was beginning to form between there and the present Little North Mountain to the west. Both the incipient trough of the Massanutten Mountain area and the arch to the west were superimposed on the regional northwesterly paleoslope that existed because of the Taconic orogeny. Thus the Massanutten Mountain area was a linear trap for quartz sand and gravel which diverted many, though not all, streams to the northeast. The incipient arch to the west resulted in the deposition of thinner, finer grained quartz sand deposits of streams flowing in directions partially influenced by the structural high. Near the middle of this regressive, alluvial deposition sequence, a transgression to within a few miles of the Massanutten Mountain area resulted in shallow marine deposition of the sandy shales of the Rose Hill Formation. Following this, regression again occurred, resulting in the deposition of the Keefer Sandstone, equivalent to the upper part of the Massanutten Sandstone.

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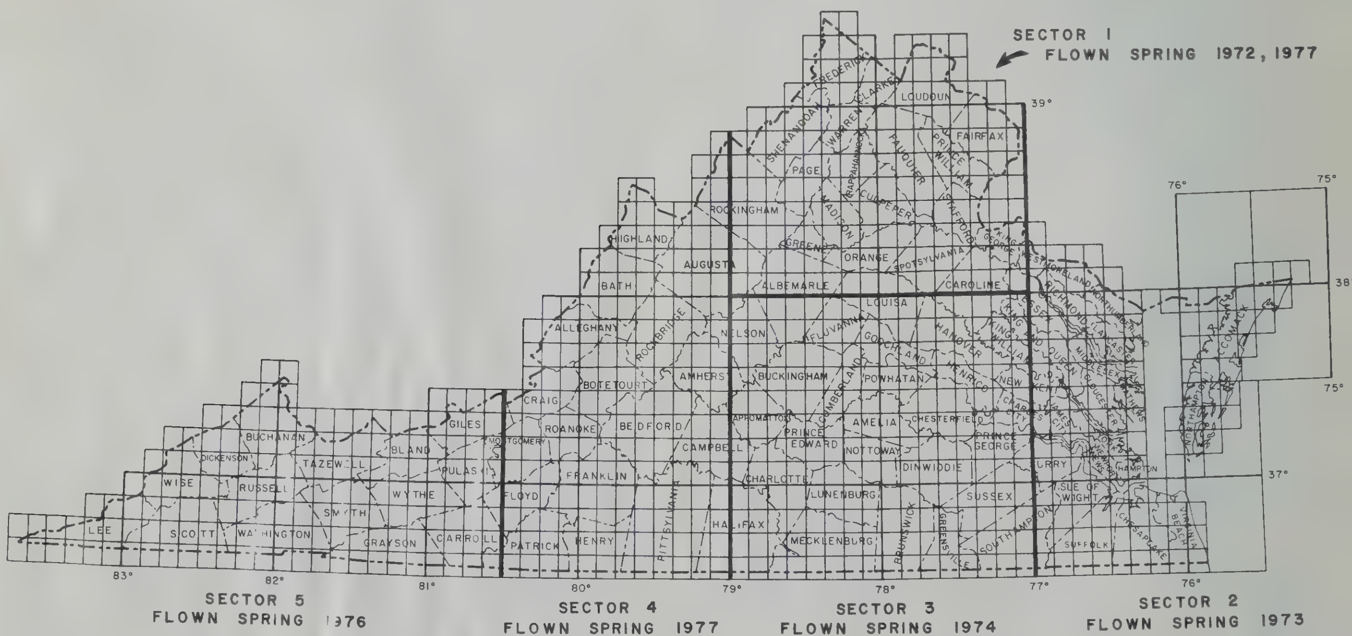
NEW AERIAL MAPPING PHOTOGRAPHY

High-altitude, quad-centered black and white aerial photography, taken during the spring of 1977, is now available for revision inspector sectors 1 and 4. These photographs are used as an evaluation source to determine which 1:24,000-scale topographic maps need to be revised. Maps of growth areas are to be updated each 5 years. As shown on the accompanying index map these sectors occupy the north-central and western portions of the Commonwealth. They include the following cities: Alexandria, Arlington, Bedford, Buena Vista, Charlottesville, Clifton Forge, Covington, Danville, Fairfax, Falls Church, Fredericksburg, Harrisonburg, Lexington, Lynchburg, Martinsville, Roanoke, Salem, and Staunton. Except for 11 quadrangles, photographs of this type are available for all 1:24,000-scale map areas in the Commonwealth. In Sector 1 growth features can be interpreted by comparison of this photography with that taken in 1972.

This photography is available as a series of overlapping prints from which stereo studies, in which the landscape appears to be three dimensional, can be made. Within the series of photographic prints there are single photographs which are uniquely centered on each 1:24,000-scale topographic map area depicted. These quad-centered 9 x 9 inch prints are about one third the size of the maps. Three-times enlargements of the prints at a size of 28 x 28 inches, when compared with the corresponding topographic maps, aid in interpretation of features on both maps and prints. Photographs are especially useful for determining types of vegetation, land use, and property lines. Photographic reproductions of prints and enlargements can be obtained *only* from the National Cartographic Information Center-East, Mail Stop 536, U. S. Geological Survey, Reston, VA 22092. As ordering aids for these quad-centered photographs, a listing of topographic maps with their respective photographs and an index showing map name and locations can be obtained on request from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; this office also sells topographic maps.

HIGH-ALTITUDE QUAD-CENTERED PHOTOGRAPHY
REVISION INSPECTION SECTORS



NEW PUBLICATION SERIES

The Bulletin, Mineral Resources Report, Report of Investigations, and Information Circular series of publications have been discontinued by the Virginia Division of Mineral Resources. All geologic reports will hereafter be in the newly established Publication series. Due to printing schedules, the reports in the Publication series may not be released in chronological order. The last reports in the previous series were Bulletin 86, Mineral Resources Report 13, Report of Investigations 45, and Information Circular 20.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addressees.)

LIST OF PUBLICATIONS (1977-78), 41 p. No charge.

Publication 2. GEOLOGY OF THE BLAIRS, MOUNT HERMON, DANVILLE, AND RINGGOLD QUADRANGLES, VIRGINIA, by William S. Henika; 45 p., 2 maps in color, 30 figs., 5 tables, 1977. Price: $8.50 plus $0.34 State sales tax, total $8.84.

The Blairs, Mount Hermon, Danville, and Ringgold 7.5-minute quadrangles are located in the Piedmont physiographic province, Pittsylvania County, Virginia just north of the Virginia-North Carolina boundary. Precambrian metamorphic rocks are divided into two areas by the Danville basin that contains Triassic sedimentary rocks assigned to the Dry Fork Formation. Southeast of the Danville basin the Precambrian Shelton Formation, exposed in antiformal and synformal folds, forms the core of a large, refolded nappe. Precambrian metamorphosed volcanic-sedimentary rocks overlie the Shelton Formation.

The report includes two geologic maps in color at the scale of 1:24,000 (1 inch equals approximately 0.4 mile or 0.6 km). They show the Precambrian, Triassic, and Quaternary surface geologic units and environmental geology information.

Northwest of the Danville basin the Precambrian metamorphosed Fork Mountain Formation is the major rock unit. It is part of a mass of rocks that have also been deformed in a refolded nappe. The Fork Mountain formation and the metamorphosed volcanic-sedimentary rocks have been intruded by ultramafic rocks and granite dikes and sills.

Crushed stone and sand are produced. Other rocks and minerals of potential economic interest include shale, talc and soapstone, kyanite, sillimanite, and gold.

Environmental geology information for decisions concerning land use and modification is provided by derivative maps prepared from geologic data such as rock type, depth of weathering, soil type, and slope stability as well as present-day land-use patterns.

Publication 6. BOUGUER GRAVITY IN SOUTHWESTERN VIRGINIA, by Stanley S. Johnson; 27 p., 2 maps (1 in color), 1 fig., 1977. Price: $2.00 plus $0.08 State sales tax, total $2.08.

An area of approximately 5,300 square miles (13,727 sq km) in Virginia, bounded by 81°00′ west longitude on the east and the Virginia state line on the north, west, and south, was surveyed using gravimeter methods. A total of 1,440 stations, such as bench-mark, checked spot, and bridge elevations were occupied. The survey included areas in the Appalachian Plateaus, Blue Ridge, and Valley and Ridge physiographic provinces. Precambrian and Paleozoic metamorphic and igneous rocks and Paleozoic sedimentary rocks are present in the area surveyed.

A Bouguer gravity map in color at the scale of 1:250,000 (1 inch equals approximately 4 miles or 6 km) and a map showing major regional structures are included.

Correlation was found to exist between the gravity and magnetic fields. From the gravity data it seems that there is overall fairly deep basement with a gradual deepening of the basement from the northwest to the southeast. Major faulting does not appear to be present in the basement rocks (thin-skinned tectonics) as based on the absence of sharp and steep gradients.

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ADDITIONS TO STAFF

Mr. Michael L. Upchurch joined the Division staff on November 16, 1977 and will assist in the information service and topographic mapping section. He received his B.S. in geology from East Carolina University, M.S. in petrology from the University of North Carolina, and M.A.T. in education from Duke University. He was previously employed as an oceanographer and then as an earth science teacher in North Carolina before joining the Division.

Mr. Mark P. Phillips joined the Division staff on January 16, 1978 and has been assigned to the information service and topographic mapping section. He received his B.A. in geology from Albion College, Albion, Michigan in 1972 and M.S. in geology from the University of Arizona in 1976. Previous to joining the Division, he taught at Wayne State University in Detroit, Michigan.

NOTE: No revised 7.5-minute topographic quadrangle maps were published from September 15, 1977 through January 15, 1978. However, total state coverage of topographic maps is completed; index is available free. Published topographic maps for all of Virginia may be purchased for $1.25 each (plus 4 percent State sales tax for Virginia addresses) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903.

No. 2

VIRGINIA MINERALS

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THE MINERAL INDUSTRY IN VIRGINIA IN 1976[1]

ADVANCE SUMMARY

Virginia's total mineral production in 1976 was valued at $1,160,600,000, a decrease of 8 percent below that of 1975. The decline in mineral production value, the first in many years, was primarily due to a decrease in the value of bituminous coal (Table 1). However, bituminous coal continued to be the Commonwealth's leading mineral commodity; total tonnage was 39,996,000 short tons, valued at $964,669,000, an increase of 12 percent in output, but a decrease in value of 11 percent below that of 1975. It comprised 83 percent of the total mineral production value of the Commonwealth compared to 86 percent in 1975.

Production of stone, the second leading mineral commodity, increased 9 percent in tonnage and 2 percent in value over that of 1975. Other leading mineral commodities, in descending order of value, were cement (masonry and portland), lime, and sand and gravel.

Several commodities whose values are concealed increased in both output and value. Kyanite production increased 11 percent and value increased 19 percent. Gypsum production and value more than trebled while the value of talc doubled with only a slight increase in output.

Natural gas production increased 3 percent, but value more than doubled. Crude petroleum production remained about the same.

Zinc production declined 26 percent and value 30 percent; lead production decreased 24 percent and value 18 percent. Silver, recovered from the smelting of lead and zinc, declined in production and value.

[1]Prepared in the U.S. Bureau of Mines Liaison Office—North Carolina and Virginia, Raleigh, NC, under a cooperative agreement between the Bureau and the Virginia Division of Mineral Resources.

THE MINERAL INDUSTRY IN VIRGINIA IN 1977[2]

PRELIMINARY DATA (SUBJECT TO CHANGE)

Preliminary information shows that the total value of mineral production in Virginia in 1977 was $1,128,000,000 according to estimates by the U.S. Bureau of Mines (Table 1). This was a decrease of 3 percent below that of 1976. Of the total mineral value approximately 82 percent was contributed by fuels, 17 percent by nonmetals, and 1 percent by metals.

[2]Prepared in the U.S. Bureau of Mines Liaison Office—North Carolina and Virginia, Raleigh, NC, under a cooperative agreement between the Bureau and the Virginia Division of Mineral Resources.

The estimated production of bituminous coal decreased 7 percent to approximately 36,990,000 tons and output value decreased from $964,669,000 in 1976 to an estimated $910,000,000 or 5 percent in 1977. Natural gas production increased significantly, but crude petroleum production remained about the same.

Stone increased 6 percent in tonnage and 11 percent in value; sand and gravel decreased 5 percent in output and 4 percent in value; lime production was down slightly in tonnage, but value increased 13 percent; and cement tonnage and values increased moderately.

Zinc production increased 18 percent and value 10 percent over that of 1976; lead tonnage increased 13 percent and value 50 percent. Silver recovery more than doubled.

Table X.—Mineral production in Virginia.[1]

Mineral	1975 Quantity	1975 Value (thousands)	[2]1976 Quantity	[2]1976 Value (thousands)	[3]1977 Quantity	[3]1977 Value (thousands)
Clays .... thousand short tons	819	$ 1,152	862	$ 1,210	865	$ 1,443
Coal .... do	35,510	[4]1,081,587	39,996	964,669	36,990	910,000
Gem stones	NA	13	NA	12	NA	10
Lead (recoverable content of ores, etc.) .... short tons	2,551	1,097	1,946	899	2,200	1,346
Lime .... thousand short tons	705	20,192	878	25,993	839	29,480
Natural gas .... million cubic feet	6,723	3,462	6,937	7,908	8,750	10,325
Petroleum (crude) .... thousand 42-gallon barrels	3	W	3	W	2	28
Sand and gravel .... thousand short tons	9,895	24,776	[5]10,191	[5]23,089	[5]9,700	[5]22,300
Stone .... do	35,384	84,204	36,132	91,723	38,189	102,139
Zinc (recoverable content of ores, etc.) .... short tons	15,151	11,818	11,241	8,319	13,300	9,150
Value of items that cannot be disclosed: Aplite, cement (masonry and portland), gypsum, iron ore (1976), kyanite, sand and gravel (industrial, 1976, 1977), silver, talc, and values indicated by symbol W	—	33,673	—	36,823	—	41,433
Total	—	[4]1,261,974	—	1,160,645	—	1,127,654

NA Not available. W Withheld to avoid disclosing individual company confidential data.

[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

[2]Revised from figures given in *Virginia Minerals*, vol. 23, no. 1, p. 7, February 1977.

[3]Preliminary data; subject to revision.

[4]Revised from figures given in *Virginia Minerals*, vol. 22, no. 1, p. 2, February 1976 and vol. 23, no. 1, p. 7, February 1977.

[5]Excludes industrial sand and gravel; value included with "Value of items that cannot be disclosed."

REPLENISHING NON-RENEWABLE MINERAL RESOURCES—A PARADOX[1]

Richard P. Sheldon[2]

In 1922 a joint committee of petroleum geologists from the American Association of Petroleum Geologists and the U.S. Geological Survey estimated that the United States had only 9 billion barrels of oil left in the ground either as reserves or as resources to be discovered (U.S. Geological Survey, 1922). Eleven years later, the 9 billion barrels had been produced and an additional 13 million barrels had been discovered.

In 1952 the President's Materials Policy Commission estimated the Nation's foreseeable copper re-

[1]Reprinted from a portion of "United States Geological Survey Yearbook, Fiscal Year 1977", p. 41-47.

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source (as of 1950) to be 25 million tons. Twenty-five years later, 31 million tons of copper had been produced and an additional 57 million tons of reserve had been discovered.

These are two of many examples of carefully reasoned mineral resource predictions by credible highly qualified geologists and engineers that have been overtaken in a few tens of years by additional production and discovery.

Mineral resource estimates ordinarily are requested by national planners when they perceive possible future shortages. The 1922 oil estimate was made during the "John Bull" oil shortage scare, and the 1952 copper estimate was undertaken during the post-World War II period when the United States was thought to be "outgrowing its resource base." The engineers and geologists responsibly furnish these estimates, usually qualifying them as conservative, particularly in regard to minerals expected to be added by additional discovery. Unfortunately, such qualifiers are quite often dropped by many of those who use the estimates. These estimates generally deepen the concern over impending shortage, but become irrelevant when the period of shortage gives way to a period of adequate or even over supply.

Behavior of these non-renewable mineral resources over time is opposite to what we intuitively expect. Geologists and engineers measure and report resource abundance. The resources they estimate are then depleted at ever increasing rates that foreseeably should exhaust the resource. Concern about shortages grows. Yet when the time approaches when we should have run out of the resource, we find paradoxically—almost alchemically—that we have more than we started with. At best we distrust the forecaster's ability and at worst his motives. What has gone wrong? Are such underestimates going to continue to be made in the future? To answer these questions, the nature and dynamics of resources need to be understood.

NATURE OF RESOURCES

In Webster's dictionary, a resource is defined as a fresh or additional stock or store of something available at need. Thus, in the short term, we think of resources as a stockpile of inventoried material with immediate availability. If we consider long-term demand, the question of future availability becomes important, so that undeveloped resources, that is mineral resources awaiting discovery in the ground or living resources yet to be born or planted, must be considered. Thus resources have two essential characteristics: (1) a demand, and (2) an availability. Depending on the time frame being considered, the demand and the availability are either immediate or potential.

Resource demand. Potential resources are based on a projection of future demands, a process that carries some risk. For example, in view of the threatening deforestation in France in the late 17th century, the King planted an oak forest near Paris as a reserve to supply, some 200 years hence when the trees matured, oak logs for masts and timbers for warship construction. His foresight created a beautiful forest that still stands, but did little to meet the needs of the modern French Navy.

The changing nature of mineral resource demand and its affect on resources over time can be seen by considering the mineral resources of the State of Montana at two times: a thousand and ten years ago and ten years ago.

On the one hand, the stone-age Indian living in 968 in what was to become Montana had a very small but highly specialized need for stones. Each year he used a few pounds of flint and obsidian for tools, arrowheads, and axe heads, a few pounds of sandstone for mortars, a little salt and mineral dye. Their value at today's prices would be a few cents, or at his prices, a few belts of wampum. The total resources available in his shallow quarries would be worth perhaps a few thousands of dollars in our terms. Of course, he used so little of his mineral resource that their eventual depletion was of little if any concern to him.

On the other hand, the industrial-age Montanan living in 1968 had tremendous needs for minerals, and huge production facilities and mineral resources to meet them. Along with his fellow citizens from the other 49 states, the Montanan used, on the average, 20 tons of minerals a year. The value of the cumulative mineral production of Montana from 1880 up to 1960 was over 4 billion dollars, showing that Montana lives up to its name, the Treasure State. In 1968, Montana contained 52 varieties of significant mineral deposits ranging from asbestos to vermiculite (U.S. Geological Survey, 1968). The most important of these were oil, natural gas, coal, copper, phosphate rock, and chromium. Their reserves at that time were worth 1.17 trillion dollars.

The mineral needs of the stone-age Montanan were low, and his assessed resources were correspondingly low. On the other hand, the mineral needs of the industrial-age Montanan are large and varied, but so are his mineral resources. The difference in mineral needs, supplies and resources between the two ages is staggering. It is no matter that the stone-age Montanan was standing on vast deposits of minerals that were to become highly valuable to Montanans a millenium later. To him

they were rocks to walk on, not resources to use. The separation of ages is complete when one realizes that the industrial-age Montanan does not even include among his vast mineral resources the small deposits of flint, obsidian and sandstone used by his predecessor a millenium earlier.

It is clear from considering this example that even though most mineral deposits are permanent and unchanging on the human time frame, mineral resources are temporal and changing. V. E. McKelvey pointed out (1972, p. 20) that, "Defining resources as materials usable by man, a little reflection reveals that whereas it is God who creates minerals and rocks, it is man who creates resources." One can reflect further that a mineral *deposit* can be characterized as non-newable, but mineral *resources* are another thing entirely. By additional effort by man new mineral resources can be "created," not in the sense of creation by the Almighty, but in the sense that a body of rock is identified for the first time as useable. Within the limits of geologic availability, one can conclude that the character, variety and size of mineral resources depend on the technology that needs them and the technology for developing them.

Resource availability. To be anything other than a wishful thought, resources must be available or potentially so. A mineral deposit that has been found, measured, and determined to be economically mineable at the current price using current mining and extraction technology is available and clearly a resource. If the deposit is known and measured, but no process is known or foreseen by which the material can or could be recovered economically, it is not available for use and is not a resource. However, if it seems to qualified engineers technologically feasible to develop in the future a process to recover the material economically, the deposit would be potentially available for use and would be called a sub-economic resource (U.S. Bureau of Mines, and the U.S. Geological Survey, 1976). For example, in 1950, when the 6.2 billion tons of U.S. iron ore reserve included no taconite, the low-grade taconite deposits were sub-economic and were foreseen to be only potentially available. The developing of the technology to drill, mine and concentrate taconite made it economic and, in fact, the preferred ore, which in 1975 made up most of the U.S. iron ore reserve of 17 billion tons.

Another factor of availability is the knowledge of the existence of a deposit. It is obvious that a deposit must be identified to be available and that an undiscovered deposit is unavailable. Exploration and resource geologists can identify areas where undiscovered deposits might occur and then can make a knowledgeable guess about how many deposits exist there, and of these how many might be discoverable. They also can make knowledgeable guesses about the size of such undiscovered deposits. Such deposits can then be considered potentially available; that is we have the potential to discover them with current exploration techniques. Nearly all of our known deposits that now make up our past production and present mineral reserve were once a part of the undiscovered but discoverable resource.

There is no way in which the ultimate amount of the undiscovered resources can be determined even though some portions of the ultimate amount can be estimated. We can predict a discoverable portion of undiscovered resources using well supported *hypotheses* of the occurrence of deposits, as well as an additional discoverable portion using poorly supported *speculations* on the occurrence of deposits. These portions make up the *hypothetical* and *speculative* categories of undiscovered resources used by the Geological Survey and the Bureau of Mines. However, a still further portion of undiscovered ultimate resources cannot be predicted because it is undiscoverable using either current or forseeable future exploration technology. For example, some rocks of the western United States are mineralized where they are exposed, but in large areas where they are covered by younger lava flows, they cannot be prospected for by anything other than the too-expensive drill or shaft. Geologists can confidently predict that many deposits exist beneath the lava flows but the deposits are not economically discoverable with present or foreseeable future technology and cannot be counted as a part of our resources. A still further portion of undiscovered ultimate resources cannot be predicted because of lack of scientific evidence of the existence of the deposits. Such deposits probably exist but are unsuspected by geologists. A clear hindsight example of such a deposit is the Red Sea metalliferous mud. On February 17, 1965, marine geologists on the oceanographic research vessel, *R. V. Atlantis, II,* were astonished to find that a core of mud taken in the central part of the Red Sea was enriched in zinc, copper, lead, silver, and gold (Degens and Ross, 1969). Subsequent surveys showed that the metalliferous muds in the Red Sea are widespread, fairly thick and contain large quantities of scarce metals. These deposits now are a part of the world's sub-economic resource, but there was no reason whatever before their chance discovery to suspect that they existed. They were totally unconceived and were certainly not visualized as a part of undiscovered resources.

RESOURCE FLOW

A common but incorrect way of viewing mineral resources is to regard them as the sum of the known and predicted economic deposits of commodities in current use, and from that to conclude that mineral resources in general are fixed and non-renewable. As seen in the discussion in the previous section, mineral resources consist of known and suspected mineral deposits that are counted as resources by virtue of industrial needs for them and subsequently are categorized according to knowledge of their existence, the economics and technology of their discovery, and the economics and technology of their mining and extraction. These factors change over time, causing the make-up and magnitude of resouces to change. Recognizing that resources are so heavily influenced by these temporal economic factors, economists David Brooks and P. W. Andrews pointed out in 1974 that in matters of long-term supply, minerals should be treated not as a fixed stock, but as a flow that responds to demand.

The misconception of resources as a fixed stock answers part of the question raised at the start of this paper, "What has gone wrong with our mineral forecasting?" At a time of concern over threatening shortages of minerals, resource geologists and engineers are asked to join forces and estimate the known mineral resources and predict the unknown mineral resources. They would like to estimate once and for all the total or ultimate resources of the country, but they cannot. Their problem is this—both geologists and engineers, no matter how technically liberal they may be, must stay within the confines both of their data and their technical understanding and methodology. They come up with estimates, but each one is outdated the day it is published, because continuing exploration and study generate new data, and new basic research sparks new ideas of occurrence or recovery. In the past, most estimates have turned out to be too low, which is expectable. Regardless of the liberalism of the estimater, the methodologic conservatism that must be followed insures that the estimate will exclude deposits that are unrecoverable with foreseeable technology as well as deposits that are undiscoverable—as were the mineral deposits beneath basalt flows—or are unpredictable—as were the Red Sea metalliferous muds. Over time with the accumulation of more knowledge, significant amounts of such deposits will become recoverable, discoverable or predictable and add to the total resources.

This is not to say that rocks, minerals, and their natural concentrations are not finite or that geologic availability is not a limiting factor in resource magnitude, but only that the conception and perception of resources at any given time are likely to be limited.

MINERAL SUPPLY SYSTEM

The mineral supply system of the United States yields this flow of most mineral materials from one resource category to another progressively from speculative-undiscovered resources to refined material production. As we have seen, the system is driven by the demands of the industrial-age.

To understand how this supply system works and the factors influencing it, one must look at its components. It is commonly conceived to have three major phases: research, exploration, and exploitation; however, each of these phases is divided into two parts. Research consists of conception and assessment of undiscovered resources; exploration consists of discovery and delineation of mineral deposits; and exploitation consists of extraction and processing of ores. Table 2 shows this breakdown along with the actual activity carried out, the mineral resource category developed, and the institutions with the prime responsibility.

The flow of material is initiated by research organizations in government, academic, and the private sector conducting basic research on geologic processes of rock and mineral formation and distribution. Originally all resources were unconceived, and only by such basic study and thinking was each kind of deposit conceived. Once conceived, the magnitude, location and character of the deposits are speculated on and reported as a *speculative* undiscovered resource, generally by government and academic research organizations.

In the next phase, mineral resources are further defined by government resource agencies and to a lesser degree (and mainly for its own purposes) by the exploration sector of industry. They conduct geologic,geophysical, and geochemical mapping of areas of speculative resources. Application of well-supported hypotheses concerning the occurrence of mineral deposits to these regional data allows estimation of *hypothetical undiscovered resources.* In this way the certainty of actual existence of the undiscovered resource is increased to the point that the hypothetical resource estimates have sufficient reliability for national planning in government or exploration planning in industry.

At this point exploration is initiated by industry. The regional maps produced at the assessment stage are used to plan a prospecting program. More detailed field studies are carried out to narrow the target areas, and finally drilling or tunneling is undertaken to search for the deposit. This activity, when

Table 2.—Phases of mineral supply system.

Major phases	Detailed phases	Activity	Mineral resource category developed		Prime responsibility
RESEARCH	CONCEPTION	Research in geologic processes, i.e. plate tectonics, formation of mineral deposits, etc.	UNDISCOVERED RESOURCES	SPECULATIVE	Universities, Government, research organizations, private institutes
	ASSESSMENT	Geologic, geophysical, and geochemical mapping, geostatistical analysis		HYPOTHETICAL	Government Industry
EXPLORATION	DISCOVERY	Prospecting	RESERVES	INFERRED	Industry
		Research on prospecting techniques			Government and Industry
	DELINEATION	Exploration		INDICATED AND MEASURED	Industry
		Research on exploration techniques			Industry and Government
EXPLOITATION	EXTRACTION	Mining and land reclamation	Produced raw material		Industry
		Research and development on extraction	Reserves		Industry and Government
	PROCESSING	Beneficiation reduction and refining	Produced refined material		Industry
		Research and development on processing	Reserves		Industry and Government

successful, develops *reserves* of the *inferred* class. Further detailed exploration improves the accuracy of the reserve estimate by better delineating the extent and shape of the deposit as well as its grade and mineralogy. This activity develops *indicated and measured reserves* which have the degree of certainty necessary for the investment by industry of large amounts of capital needed for exploitation of the deposit.

The mineral supply system consists of a series of sequential steps, each one necessary for the initiation of the succeeding step, and each one designed to improve the effectiveness and economic efficiency of the total system. The demand for minerals drives the resource flow. The overall economic efficiency of this system is set by the technologic level and is improved by research and development at all phases. That is to say, the estimated magnitude of undiscovered resources is increased by improved basic concepts of mineral deposits and mapping and resource assessment of potentially mineralized areas. Reserves are increased by prospecting, which is made more effective by improvement of prospecting, extraction and processing techniques. The increase in resources over time is directly related to the amount of effort put into improving the technology as well as to the amount of exploration effort. That is to say, we replenish, expand and diversify our "non-renewable" mineral resources by technologic advance through research and development effort.

LONG-TERM MINERAL SUPPLY

Our mineral resources are replenished by scientific and technologic advance, but how long can this keep up? Even with replenishment, will we eventually outgrow our mineral resource base? Much thought has been given to this question and much diversity of opinion exists. Economic geologist, B. J. Skinner, in an article titled, "A second iron age ahead?" (1976) predicts that the day when "we will have to come to grips with the way in which the earth offers us its riches . . . is less than a century away, perhaps less than a half century. When it dawns we will have to learn to use iron and other abundant metals for all our needs." On the other side, resource economist, J. F. McDivitt (1974) believes that ". . . if the peoples of the world continue to work closely together and to move towards an ever more efficient pattern of resource use . . .

mineral shortages will continue to be only a faint cloud on the world's horizon."

The mineral supply system certainly will have to deal in the long term with serious constraints if it is to keep up with demand. First of all, demand itself has been growing exponentially and, of course, that sort of growth cannot continue. Brooks and Andrews (1974) have suggested that "relative demands (for minerals) decline after a point with increase in per capita income. Indeed . . . the relative growth is sufficiently damped that it was suggested in one study that mineral production will need to grow less fast in the future than it has grown in the recent past, exactly the opposite of most conclusions based on trend analysis." This is the same sort of hopeful sign that in recent years we have witnessed in some population growth in reaction to increased per capita income. Another constraint to the long-term mineral supply system is a threatened shortage of energy. Much of the technologic advance that replenishes mineral resources is energy intensive, so this could be a serious future contraint and in fact, the rise in energy costs in the last years has been severely felt in most parts of the mining industry. Another present major constraint that could increase even more is the accommodation of the mineral supply system to the regulatory controls and costs concerned with environmental pollution and degradation as well as to the public desire to withdraw from mineral entry all public lands judged better used as a wilderness or an ecologic reserve. Another possible constraint is what B. J. Skinner calls the "mineralogical barrier." Scarce metals in the earth's crust, such as copper, lead, nickel, tin, and tungsten, are mostly disseminated within the atomic structure of host minerals that make up common rock. In that way they are accessible to recovery only by chemically breaking down the host minerals, a feat which requires very large amounts of energy. Such scarce metals are now recovered from the geologically rare deposits in which they occur as a principal component. Geologist Skinner believes that such deposits will soon be depleted. Economists Brooks and Andrews argue against this concept by holding that "every bit of evidence we have indicates the existence of mineral resources (at lower grades) that could be mined and, further, that either as their price goes up or as their cost goes down (which is to say, as technology of extraction improves), the volume of mineable material increases significantly—not by a factor of 5 or 10 but by a factor of 100 or 1,000." The arguments on this critical issue could be better focused by additional scientific information on the amounts of mineralized rock available at different grades, because existing data are too limited for definite conclusions. Thus, it is not certain that the geologic availability of lower grade resources to the mineral resource supply system is assured so a potential barrier to the resource system remains.

Whether the mineral resource supply system can overcome these restraints in the long run depends ultimately on the magnitude of those mineral resources that we cannot now assess. They are the resources that we are unable to conceive or for which we are unable to foresee the discovery or recovery techniques. There is no question that the resources we know about are a fixed stock and eventually will run out. But, can they be replaced?

Another way of posing this problem is to ask the question whether or not an equilibrium of mineral use can be established that will last indefinitely or nearly so. If the real world of supply and demand is likened to a model where mineral resources are fixed and demand is dynamic and expanding, minerals will run out. But this model is not like the real world where supply and demand are dynamically inter-related and mineral shortages set off a whole set of changes including higher prices, reduced demand, increased conservation, increased substitution, increased recycling, increased technologic and scientific research, increased exploration and increased exploitation of lower grades ores. In the real world, mineral use has evolved to overcome such shortages as firewood from depleted forests, or copper from mined out high grade veins, and such evolution will continue to operate as new shortages arise. This is not to say that such minerals as petroleum in conventional fields, and presently economic deposits of mercury, helium, platinum, and other such geologic rarities will not be exhausted eventually. But our technology likely will evolve to accommodate to a lesser or more expensive supply of such minerals, much as it has developed without abundant supplies of the metals praeseodymium, neodymium, promethium, gadolinium, terbium, and the other rare earths, which were they abundant, probably would be used widely.

Mineral economist John E. Tilton in his excellent book, *The Future of Nonfuel Minerals*, concluded:

> In the more distant future--the twenty-first century and beyond—depletion could become a more pressing problem. It is important to stress this possibility, for the consequences to industrial societies could be more severe. At the same time, it should be noted that the arsenal available to mankind for dealing with this threat is not empty. As pointed out above, public policies that support research in

minerals and reduce their consumption increase the likelihood that technological progress will continue to offset the adverse effects of depletion. Other policies, such as programs to encourage smaller families, to slow the growth of population, may be desirable for other reasons as well. Finally, even in the absence of such policies, one cannot be certain that depletion will ultimately overwhelm the cost-reducing impact of new technology. For as depletion starts to push mineral prices up, it unleashes forces that stimulate the substitution of cheaper and more abundant materials for the increasingly scarce minerals, encourages the search for new and unconventional sources of supplies, and promotes the development of more cost-reducing technologies. Conceivably, these forces could by themselves keep the spector of depletion at bay indefinitely.

It seems clear that our long-term mineral supply system is much stronger than believed by the analysts who regard mineral resources as a fixed and essentially known and fully conceived stock. At the same time, we have the responsibility of keeping the system healthy, and some steps should be taken to do so. The workings of the mineral resource system in its full complexity needs examination to better understand the factors that affect it. A statistical monitoring series that would give early warning of a weakening in the resource replenishment process in any part of the system should be devised and set up. Finally, adequate research and development should be carried out in order to strengthen weak parts of the mineral supply system.

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BASEMENT WELLS IN THE COASTAL PLAIN OF VIRGINIA

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The following catalog of wells drilled to basement in the Coastal Plain of Virginia includes only those for which samples are on file at the Division of Mineral Resources. Basement is defined as Precambrian(?) to Paleozoic igneous and metamorphic rock and Triassic sedimentary rock underlying unconsolidated to semiconsolidated Cretaceous through Quaternary sediment. The majority of the borings were made to obtain water; however, a few exploratory holes are included. In general the exploratory drillings are the deeper ones. The listing (Table 3) is arranged by Division respository number (W-56), county number (211), county, 7.5-minute quadrangle, longitude and latitude, total depth, depth to basement and basement rock type. Foot notes refer to published references.

Table 3.—Basement wells in the Coastal Plain of Virginia.

Well Repository No./ County No.	County/ Quadrangle	Latitude	Longitude	Total Depth/ Basement Depth (feet)	Basement Rock Type
W-56/211	Richmond (City)/Drewrys Bluff	37°27′26″	77°25′28″	425/71	Granite
W-70/4	Dinwiddie/Petersburg	37°08′27″	77°24′13″	173/170	Granite
W-158, W-159/32, 2	Hampton (City)/Hampton	37°00′15″	77°18′23″	2255/2246	Granite
W-180/4	Mathews/Mathews	37°25′52″	77°19′42″	2325/2307	Granite[2, 3]
W-457/32	King William/Manquin	37°41′45″	77°12′38″	3278/1009/2609	Red mudstone[6], granite gneiss[3]
W-515/132	King William/West Point	37°32′43″	76°48′22″	1689/1320	Red sandstone, arkose[5], siltstone
W-539/323	Henrico/Yellow Tavern	37°38′34″	77°29′21″	239/26	Granite gneiss
W-584/208	Chesterfield/Chester	37°20′58″	77°23′08″	300/260	Granite
W-587/74	Caroline/Woodford	38°01′34″	77°29′30″	297/70	Granite gneiss
W-616/325	Henrico/Drewrys Bluff	37°28′15″	77°22′38″	712/249	Sandstone[6]
W-763/36	Greensville/Emporia	36°40′35″	77°32′44″	265/60	Marble
W-781/53	Stafford/Fredericksburg	38°19′31″	77°28′27″	226/185	Granite gneiss
W-935/142	Chesterfield/Chester	37°23′14″	77°34′48″	199/150	Granite
W-953/46	Stafford/Fredericksburg	38°21′52″	77°27′19″	350/180	Granite
W-960/47	Stafford/Fredericksburg	38°22′01″	77°27′11″	325/125	Granite
W-961-48	Stafford/Fredericksburg	38°21′58″	77°26′51″	475/275	Granite
W-969/64	Hanover/Seven Pines	37°36′45″	77°21′03″	608/276	Granite[1]
W-997/37	Greensville/Skippers	36°32′50″	77°31′43″	220/44	Granite
W-1116/22	Caroline/Guinea	38°07′37″	77°29′00″	318/145	Granite
W-1123/172	Henrico/Richmond	37°32′40″	77°22′58″	262/257	Granite[1]
W-1187/24	Dinwiddie/Petersburg	37°11′14″	77°28′33″	126/100	Granite
W-1194/23	Dinwiddie/Petersburg	37°09′35″	77°25′47″	175/95	Granite[5]
W-1198/145	Chesterfield/Chesterfield	37°28′10″	77°33′46″	600/50	Granite
W-1210/276	Prince William/Occoquan	38°39′49″	77°15′05″	577/90	Granite gneiss
W-1230/55	Stafford/Stafford	38°25′30″	77°24′26″	295/210	Granite
W-1297/148	Chesterfield/Drewrys Bluff	37°23′17″	77°25′40″	234/158	Granite
W-1300/80	Hanover/Yellow Tavern	37°39′27″	77°23′17″	334/290	Granite
W-1305/178	Henrico/Yellow Tavern	37°37′54″	77°25′28″	508/200	Granite[1]
W-1388/82	Hanover/Yellow Tavern	37°39′26″	77°23′41″	525/324	Granite
W-1472/83	Hanover/Richmond	37°36′20″	77°22′38″	395/260	Granite[1]
W-1477/184	Henrico/Richmond	37°33′07″	77°23′21″	227/190	Granite[1]
W-1507/25	Dinwiddie/Petersburg	37°08′41″	77°31′18″	108/30	Granite
W-1508/163	Chesterfield/Drewrys Bluff	37°23′49″	77°24′51″	393/130	Granite gneiss[5]
W-1510/160	Prince George/Petersburg	37°11′50″	77°22′42″	224/160	Granite
W-1533/86	Hanover/Ashland	37°45′14″	77°28′05″	295/90	Granite
W-1534/87	Hanover/Ashland	37°45′14″	77°28′05″	350/104	Granite
W-1541/155	Chesterfield/Drewrys Bluff	37°24′41″	77°25′58″	402/70	Granite
W-1553/88	Hanover/Ashland	37°45′14″	77°28′05″	230/104	Granite
W-1634/199	Isle of Wight/Franklin	36°41′49″	76°54′21″	925/913	Granite[2]
W-1687/92	Hanover/Ashland	37°45′14″	77°28′05″	132/98	Granite
W-1753/28	Dinwiddie/Petersburg	37°11′04″	77°24′13″	400/175	Granite
W-1791/99	Hanover/Yellow Tavern	37°38′30″	77°23′26″	632/320	Granite gneiss[1]
W-1800/101	Hanover/Yellow Tavern	37°38′51″	77°24′13″	708/250	Granite[1]
W-1878/104	Hanover/Yellow Tavern	37°40′38″	77°25′51″	640/170	Granite[1,5]
W-1906/172	Richmond (City)/Drewrys Bluff	37°28′32″	77°27′28″	78/20	Granite
W-1907/30	Dinwiddie/Petersburg	37°11′50″	[illegible]27′46″	118/50	Granite
W-1908/171	Chesterfield/Chester	37°18′41″	7[illegible]4′06″	140/120	Granite[5]
W-1921/164	Prince George/Carson	37°02′30″	77[illegible]′14″	4[illegible]0/90	Arkose[2,5,6]
W-1936/31	Petersburg (City)/Petersburg	37°12′17″	77°2[illegible]′04″	143/140	Granite
W-2068/106	Hanover/Yellow Tavern	37°42′24″	77°28′01″	322/83	Granite[1]
W-2071/196	Henrico/Richmond	37°31′00″	77°14′03″	652/640	Sandstone[5,6]
W-2221/110	Hanover/Yellow Tavern	37°41′35″	7[illegible]°25′48″	300/185	Granite
W-2227/80	Caroline/Ladysmith	38°01′10″	7[illegible]°30′05″	154/60	Granite
W-2229/469	Spotsylvania/Spotsylvania	38°07′53″	7[illegible]°30′16″	35[illegible]/50	Granite
W-2237/93	Hanover/Richmond	37°37′06″	77°23′50″	260/188	Granite[1]
W-2248/113	Hanover/Ashland	37°45′13″	77°28′09″	218/100	Granite[1]
W-2[illegible]3	Sussex/Manry	36°58′46″	77°00′24″	886/770	Phyllite, schist[2,5]
W-2[illegible]7	Hanover/Richmond	37°36′36″	77°23′32″	600/220	Granite[1]
W-247[illegible]8	Hanover/Yellow Tavern	37°44′15″	77°26′42″	282/[illegible]05	Granite[1]
W-250[illegible]/12[illegible]	Hanover/Yellow Tavern	37°40′29″	77°25′42″	[illegible]53/[illegible]65	Granite
W-2655/128	Hanover/Yellow Tavern	37°40′10″	77°25′51″	310/[illegible]0	Granite
W-2656/129	Hanover/Yellow Tavern	37°40′05″	77°25′36″	136/1[illegible]2	Granite

W-2683/199	Henrico/Seven Pines	37°31′38″	77°18′23″	540/510	Sandstone[1,6]
W-2751/34	Dinwiddie/Dinwiddie	37°06′21″	77°32′17″	330/78	Granite
W-2756/136	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/69	Granite
W-2757/135	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/103	Granite
W-2841/139	Hanover/Yellow Tavern	37°39′21″	77°22′35″	451/306	Granite[1]
W-2926/137	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/60	Granite[1]
W-2927/36	Dinwiddie/Dinwiddie	37°04′30″	77°35′06″	335/112	Granite
W-2932/200	Henrico/Richmond	37°35′00″	77°29′18″	400/30	Granite[1]
W-3088/196	Chesterfield/Chester	37°20′54″	77°23′08″	372/220	Granite
W-3180	Accomack/Hallwood	37°53′03″	75°31′00″	6272/6018/6134	Red shale[4,6], prophyroblastic argillite
W-3320/226	Sussex/Littleton	36°58′24″	77°09′02″	554/500	Granite[2,5]
W-3250/197	Chesterfield/Chester	37°18′43″	77°24′02″	237/140	Granite
W-3277/142	Hanover/Yellow Tavern	37°42′03″	77°27′17″	250/86	Granite[1]
W-3316/183	Nansemond/Corapeake	36°34′05″	76°35′09″	2017/1920	Sandstone[2,5,6]
W-3317	Charles City/Charles City	37°20′12″	77°06′22″	650/570	Metavolcanics[2]
W-3366/144	Hanover/Yellow Tavern	37°43′48″	77°24′44″	405/165	Granite[1]
W-3367/145	Hanover/Yellow Tavern	37°41′44″	77°26′19″	300/170	Granite
W-3411/198	Chesterfield/Hopewell	37°20′06″	77°16′53″	294/285	Phyllite
W-3443/206	Henrico/Dutch Gap	37°29′32″	77°21′01″	340/220	Sandstone[2,6]
W-3542/147	Hanover/Yellow Tavern	37°41′43″	77°26′05″	290/175	Granite
W-3570/39	Greensville/Emporia	36°41′20″	77°30′56″	225/50	Granite gneiss
W-3574/207	Henrico/Seven Pines	37°31′12″	77°16′36″	610/460	Sandstone[1,6]
W-3579/149	Hanover/Yellow Tavern	37°41′37″	77°26′28″	330/200	Granite
W-3649/153	Hanover/Yellow Tavern	37°41′33″	77°26′40″	200/27	Granite
W-3680/152	Hanover/Yellow Tavern	37°41′37″	77°26′21″	350/50	Granite
W-3791/157	Hanover/Yellow Tavern	37°38′11″	77°22′54″	431/300	Granite gneiss
W-3821/102	Caroline/Bowling Green	38°00′32″	77°22′06″	592/300	Granite gneiss
W-3824/162	Hanover/Yellow Tavern	37°40′21″	77°25′31″	310/68	Granite
W-3876/113	Charles City/Charles City	37°19′55″	77°05′55″	591/585	Amphibolite
W-3900	Hanover/Studley	37°42′48″	77°17′58″	504/500	Granite[1]
W-3901	Hanover/Studley	37°40′55″	77°17′45″	627/527	Granite[1]
W-3902	Hanover/Richmond	37°36′43″	77°24′23″	159/155	Granite[1]
W-3903	Henrico/Seven Pines	37°31′04″	77°20′39″	404/280	Mudstone[1,6]
W-3904	Hanover/Seven Pines	37°37′00″	77°15′55″	600/512	Mudstone[1,6]
W-4069/40	Greensville/Jarratt	36°49′02″	77°28′29″	340/111	Phyllite
W-4159/174	Hanover/Ruther Glen	37°52′53″	77°27′48″	297/37	Mudstone[6]
W-4162/218	Chesterfield/Beach	37°17′07″	77°34′46″	505/70	Granite
W-4208/170	Hanover/Ashland	37°50′56″	77°26′39″	420/229	Mudstone[6]
W-4387/110	Caroline/Ladysmith	38°01′53″	77°31′07″	375/40	Granite
W-4391/179	Hanover/Yellow Tavern	37°37′31″	77°22′48″	320/316	Granite
W-4394/178	Hanover/Yellow Tavern	37°39′59″	77°24′42″	367/260	Granite
W-4397/212	Richmond (City)/Drewrys Bluff	37°27′28″	77°25′16″	292/290	Granite gneiss
W-4505/112	Caroline/Ruther Glen	37°58′22″	77°29′11″	445/40	Granite
W-4540/214	Chesterfield/Chester	37°15′56″	77°24′38″	240/40	Granite
W-4541/42	Greensville/Emporia	36°42′31″	77°31′16″	206/60	Metasiltstone
W-4762/215	Chesterfield/Drewrys Bluff	37°25′15″	77°25′02″	205/176	Granite
/5	Caroline/Bowling Green	38°03′05″	77°20′45″	1550/533	Sandstone[6]

FOOTNOTES

[1]Daniels, P.A., Jr., and Onuschak, Emil, Jr., 19 4, Geology of the Studley, Yellow Tavern, Richmond, and Seven Pines quadrangles, Virginia: Virginia Division of Mineral Resources Rept. Inv. 38, 75 p.

[2]Johnson, S. S., 1975, Bouguer gravity in southeastern Virginia: Virginia Division of Mineral Resources Rept. Inv. 39, 42 p.

[3]Le Van, D. C., 1962, Wells drilled for oil and gas in Virginia prior to 1962: Virginia Division of Mineral Resources, Mineral Resources Report 4, 47 p.

[4]Onuschak, Emil, Jr., 1972, Deep test in Accomack County, Virginia: Virginia Minerals, vol. 18, no. 1, p. 1-4.

[5]Teifke, R. H., 1973, Stratigraphic units of the Lower Cretaceous through Miocene series, *in* Geologic studies, Coastal Plain of Virginia: Virginia Division of Mineral Resources Bulletin 83, pt. 1, p. 1-78.

[6]Triassic rocks.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addressees.)

Publication 4. GEOLOGY OF THE GREENFIELD AND SHERANDO QUADRANGLES, VIRGINIA, by Mervin J. Bartholomew; 43 p., 2 maps in color, 37 figs., 5 tables, 1977. Price: $6.00 plus $0.24 State sales tax, total $6.24.

The Greenfield and Sherando 7.5-minute quadrangles, encompassing an area of about 118 square miles (306 sq km), are located in the Blue Ridge, Piedmont, and Valley and Ridge physiographic provinces in Albemarle, Augusta, and Nelson counties, Virginia. A 1- to 3-mile- (2- to 5-km-) wide zone of cataclastic rocks bisects approximately the area from the north-central part of the Greenfield quadrangle southwestward to the southeastern part of the Sherando quadrangle. East of this zone, layered gneiss with northwestward-trending segregation layering was metamorphosed to granulite facies and partially melted during emplacement of massive Lovingston granitic gneiss; both rock units were intruded by massive charnockite during Grenville metamorphism. West of the cataclastic zone, layered gneiss with eastward-trending segregation layering was metamorphosed to granulite facies and intruded by Grenville-age massive charnockite of the Pedlar Formation. The late Precambrian(?) Swift Run and Catoctin volcanic sequence overlies the latter rocks. This volcanic sequence is overlain by the Cambrian clastic and carbonate sequence of the Weverton, Harpers, Antietam, Shady, and Waynesboro formations. These Cambrian rocks occur beneath and adjacent to extensive Quaternary sediments to the northwest of the Blue Ridge in the northwest corner of the Sherando quadrangle. Mafic dikes intruded the area prior to Paleozoic metamorphism and during the Triassic Period.

Thrusting along the Rockfish Valley fault and cataclasis in the zone of cataclastic rocks east of the fault occurred concurrent with regional Paleozoic greenschist-facies metamorphism that produced prominent, overturned to recumbent folds and associated axial-plane foliation. These structures were truncated by younger Paleozoic thrust faults that predate late Paleozoic(?), northeastward-trending, high-angle faults and broad, open, northwestward-trending fold axes. The youngest structures are northwestward-trending, high-angle faults mostly covered by Quaternary sediments.

Currently, there is no mining of mineral deposits in the Greenfield and Sherando quadrangles. Iron and manganese, manganese, and copper were mined sporadically within the Sherando quadrangle from the early 1800's to the middle part of the 1900's at the Mount Torry tract, the Lyndhurst mine, and the Allen mines, respectively.

The report includes two geologic maps in color at the scale of 1:24,000 (1 inch equals approximately 0.4 mile or 0.6 km). They show the Precambrian, Cambrian, Triassic, and Quaternary surface geologic units.

Map. GRAVITY MAP OF VIRGINIA—SIMPLE BOUGUER ANOMALY, by Stanley S. Johnson; color edition; scale, 1:500,000 or 1 inch equals approximately 8 miles (13 km); size, 30 x 60 inches (76 x 152 cm); 1977. Price: $3.00 plus $0.12 State sales tax, total $3.12. Additional charge for one or more unfolded copies by mail is $2.00.

The gravity map for all of Virginia is in 15 colors, each of which delineates every 10 milligals of gravity measurements of the earth. The map is based on a machine-contoured one at the interval of 5 feet. The data for the contouring is the same as that used for the 1:250,000-scale maps at the contour interval of 4 milligals in Virginia Division of Mineral Resources Reports of Investigations 27, 29, 32, 39, and 43 and Publication 6, which were published from 1971 through 1977.

Map. AEROMAGNETIC MAP OF VIRGINIA: IN COLOR, by Zietz, Isidore, Calver, James L., Johnson, Stanley S., and Kirby, John R.; published by the U.S. Geological Survey in cooperation with the Virginia Division of Mineral Resources; color edition; scale 1:1,000,000 or 1 inch equals approximately 16 miles (26 km); size 14 x 18 inches (36 x 46 cm). Price: $1.50 plus $0.06 State sales tax, total $1.56. Additional charge for one or more unfolded copies by mail is $2.00.

The aeromagnetic map of all of Virginia is in 12 colors, each of which delineates every 100 gammas of the total intensity magnetic field of the earth. The data for the contouring for most of the State is from unpublished surveys by the Virginia Division of Mineral Resources during 1962 and 1969-1972 and the U. S. Geological Survey during 1960 and 1972.

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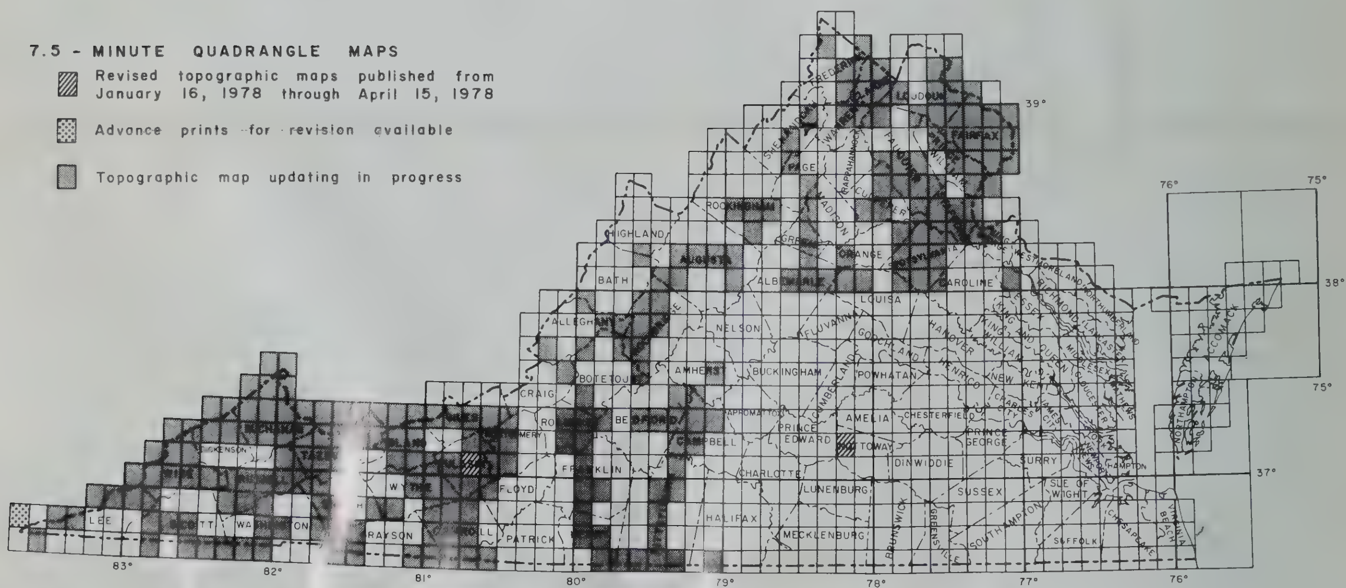
TOPOGRAPHIC MAPS



Revised 7.5-minute quadrangle maps published from January 16 through April 15, 1978:

Revised Maps
- Crewe West
- Dublin

Advance Prints for Revision
- Middlesboro North

ADVANCE PRINTS

Advance prints are available at $1.25 each from the Eastern Mapping Center, Topographic Division, U.S. Geological Survey, Reston, Virginia 22902.

PUBLISHED TOPOGRAPHIC MAPS

Total State coverage completed; index is available free. Updated photorevised maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published maps for all of Virginia are available at $1.25 each (plus 4 percent State sales tax for Virginia residents) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903.

VIRGINIA MINERALS
COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
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STATE GEOLOGIST RETIRES

After 21 years of leadership for the Division of Mineral Resources, Dr. James L. Calver retired on June 30, 1978. During this time the Division became nationally recognized for its accomplishments that include compilation and publishing of State geologic, aeromagnetic, gravity, and mineral resources maps; gathering of geologic data for 75 quadrangle areas; installation of a seismograph to monitor earthquakes; and obtaining State-wide detailed topographic map coverage. In honor of his efforts and foresight in having geologic data obtained for the Commonwealth, the recently released Publication 7 entitled, "Contributions to Virginia Geology-III", was dedicated to Dr. Calver.

Initial efforts upon becoming State Geologist in mid-1957 were to organize reference collections as repositories for representative rocks, fossils, and well cuttings; to reorganize library holdings for easier reference; to obtain microfilm collection of theses and dissertations on Virginia geology; and to develop a geologic mapping program for data in sufficient detail for land-use planning, mineral-resources exploration, and research into Virginia geologic history.

Liaison was made with mine and quarry operators by means of periodic visits. Representative rock and mineral sets were distributed to secondary schools across the State. Information on base and

precious-metal deposits was published. Results of high-silica sand and regional coal studies suitable for commercial use were reported. Data on ground-water conditions in some counties, cities, and Federal and State parks was published.

Detailed information on rock type, structure, and potential resource is being collected in the field by quadrangle area. Recent reports contain descriptions of geologic factors that govern land modification for several Virginia cities as well as some counties. Regional stratigraphic and structural studies were made to provide data on the framework of the Coastal Plain and Piedmont areas.

Topographic maps showing cultural and natural features of quadrangle areas have been prepared for all of the Commonwealth. This is the result of an accelerated State-Federal cooperative mapping program initiated by Dr. Calver in 1962. The program was supported by citizen groups, industrial interests, and governmental agencies, at a time when only about 10 percent of the State had adequate maps. Some 805 useful products are now available for planners, engineers, and outdoorsmen. The Commonwealth of Virginia became the 10th state to have complete map coverage in 1972. By means of high-altitude photography these maps are being examined once each 5 years for revision need. Those selected for revision depict growth features in purple, which shows the dimension of time. Map products such as orthophotoquads, slope maps. county maps, and orthophoto maps have been produced for selected areas as new products for the map users benefit. A listing of map names of places, landforms, water-features and religious institutions for geographic reference was compiled. These maps are of great value in property planning, recreation, forest fire control and some several hundred other uses.

Geophysical maps for use in minerals and energy resource exploration and in studies of the geologic framework of the State were initiated. Regional aeromagnetic surveys to obtain geologic information on rock structure obsured by soil cover were started in 1962. State coverage is now available from which faults and other structures have been interpreted. Aeroradiometric surveys useful in locating concentrations of radioactive minerals and in monitoring natural radiation of the earth's surface were begun in 1975. Data from a network of more than 11,000 gravity stations were used to produce the State gravity map.

Dr. Calver has been active in a number of professional societies including the Association of American State Geologists of which he is a Past President; the Geological Society of America of which he is a Fellow; the American Association of Petroleum Geologists; the American Mineralogical Society; the American Institute of Mining, Metallurgical and Petroleum Engineers of which he is a past Chairman of the Southeastern Section of the Industrial Minerals Committee; the American Geophysical Union; the American Ceramic Society; the Appalachian Geological Society; the Virginia Academy of Science; the Geological Society of Washington; and the Seismological Society of America.

Under Dr. Calver's guidance a vital role in obtaining geologic data for the Commonwealth and translating it for many uses was realized. The Division is directly concerned with pointing out potential mineral resources which enable Virginians to maintain a high standard of living.

MINERALS RESOURCE PUZZLE

There are names of 29 important mineral resources of Virginia listed in the puzzle below. Can you spot them? The names are listed on page 27 of this issue.

E	C	G	S	A	G	L	A	R	U	T	A	N	D	F
T	N	E	A	P	B	J	E	K	V	Z	S	G	E	B
I	F	L	M	L	C	N	H	Y	P	F	L	R	H	U
M	G	A	P	I	S	G	R	A	V	E	L	E	F	S
O	R	H	H	T	P	L	D	N	B	L	E	V	A	A
L	A	S	I	E	L	H	A	I	S	D	H	L	I	D
O	N	D	B	A	S	A	L	T	M	S	S	I	Q	N
D	I	R	O	N	E	G	I	E	E	P	R	S	P	D
Q	T	C	L	A	T	B	M	C	G	A	E	L	R	I
M	E	N	I	S	M	U	E	L	O	R	T	E	P	A
S	U	E	T	I	Z	T	R	A	U	Q	S	O	V	B
T	D	S	E	V	I	E	T	I	R	D	Y	H	N	A
A	C	A	P	E	N	O	T	S	P	A	O	S	G	S
O	U	N	G	Y	C	X	I	B	L	P	F	Y	Z	E
R	F	D	M	S	G	J	D	C	N	K	V	L	I	W

OIL AND GAS DEVELOPMENT IN VIRGINIA DURING 1977[1]

A total of 8,220,185 Mcf (thousand cubic feet) of natural gas was produced in Virginia during 1977, which is an increase of 1,282,859 Mcf from 1976 production. Reported production was from 202 wells in four counties: Buchanan County, 3,624,711 Mcf; Dickenson County, 3,897,296 Mcf; Tazewell County, 692,986 Mcf; Wise County, 5,192 Mcf. Oil production in Lee County was 1,742 barrels from four wells.

Twenty three new test wells were drilled during the year and 2 old wells were deepened (Table 1). Columbia Gas Transmission Corporation drilled 9 new wells in Buchanan and Wise counties with combined footage of 40,139 feet; one old well was drilled deeper in Buchanan County for an additional 740 feet and had a final open flow of 365 Mcf. Eight of these wells were development and two were exploratory tests with all of them completed as producers. Combined final open flow from 8 wells was 10,491 Mcf; one well was to be cleaned up and one well was to be fractured. Philadelphia Oil Company drilled 5 new wells in Dickenson County for a combined footage of 25,814 feet and one old well was deepened by 783 feet; all of these wells were completed as producers. Combined final open flow from 4 wells was 3,492 Mcf; one well was to be cleaned out and one well was to be fractured. Texas

Table 1. — Summary of Virginia drilling during 1977.

Operator	Lease	Well. No.	Total Depth (feet)	Status
Buchanan County				
Ashland Oil Inc.	Clinchfield Coal Co.	077051	5,233	Gas well
Columbia Gas Transmission Corporation	Pittston Co.	9550	*4,384	Gas well
"	G. W. Yates	20301	4,789	Gas well
"	Bart Elswick	20340	4,123	Gas well
"	Pittston Co.	20343	4,628	Gas well
"	Big Sandy Coal Corp.	20439-T	3,448	Gas well
"	Howard Coleman	20467	4,741	Will fracture
"	Kentland Co.	20468	3,850	Gas well
"	Pittston Co.	20469	4,081	Gas well
"	Pittston Co.	20470	4,739	Gas well
Texas International Petroleum Corporation	C. L. Ritter Lumber Co.	I.C.—1	4,736	Gas well
"	Big Vein	I.C.—3	5,066	Gas well
"	Big Vein	I.C.—6	5,110	Gas well
"	C. L. Ritter Lumber Co.	I.C.—9	4,820	Dry hole
"	Slocum Land Corp.	I.C.—10	5,052	Gas well
Dickenson County				
Philadelphia Oil Company	Pittson Co.	P—55	4,782	Gas well
"	Pittson Co.	P—59	*5,072	Gas well
"	Pittston Co.	P—65	4,831	Cleaning up
"	Pittston Co.	P—66	4,864	Gas well
"	Pittston Co.	P—67	5,311	Will fracture
"	Letcher Mullins	P—68	6,026	Gas well
Lee County				
Lee Oil Drilling Company	Don Grabeel	1	7,209	Plugged & abandoned; 2 barrels oil per day
"	Lloyd Harris	1	1,762	Dry hole
Russell County				
Gulf Oil Corporation	W. Russell Price	1	17,003	Dry Hole
Wise County				
Columbia Gas Transmission Corporation	Penn Virginia Corp.	20338—T	5,740	Cleaning up

*well deepened

[1]Information supplied by William W. Kelly, Jr., Virginia Division of Mines and Quarries.

International Petroleum Corporation drilled 5 exploratory tests in Buchanan County for a combined footage of 24,784 feet. Four of these wells were completed as producers, with a combined final open flow of 6,392 Mcf. One test was a dry hole. Ashland Oil, Inc. drilled and completed one well in Buchanan County for a total footage of 5,233 feet; final open flow was 1,873 Mcf. Lee Oil Drilling Company drilled 2 wells (1 exploratory and 1 development) in Lee County for a combined footage of 8,971 feet; both wells were dry holes. Gulf Oil Corporation drilled a wildcat well in Russell County to a total depth of 17,003 feet. It was plugged and abandoned as a dry hole.

Four operators in Buchanan County produced 3,624,711 Mcf of gas: Ashland Oil, Inc. 470,791 Mcf; Cabot Corporation, 27,893 Mcf; Columbia Gas Transmission Corporation, 3,083,080 Mcf; and P and S Oil and Gas Corporation, 42,947 Mcf. Eight new wells were drilled and one old well was drilled deeper by Columbia Gas Transmission Corporation in Buchanan County. Footage drilled by this company totaled 35,139 feet. Combined final open flow from 8 wells was 10,491 Mcf; one well was to be fractured. Texas International Petroleum Corporation drilled 5 exploratory tests for a combined footage of 24,784 feet. Four of these wells were completed as producers with a combined final open flow of 6,392 Mcf. One test was a dry hole. Ashland Oil, Inc. drilled and completed one well with a total footage of 5,233 feet; final open flow was 1,873 Mcf.

In Dickenson County the Clinchfield Coal Company delivered 88,012 Mcf of gas to the pipelines of Kentucky-West Virginia Gas Company. Philadelphia Oil Company began production from 40 new wells and produced 2,683,884 Mcf of gas that was also delivered to the pipelines of Kentucky-West Virginia Gas Company. Philadelphia Oil Company drilled 5 new development wells for a combined footage of 25,814 feet and one old well was deepened by 783 feet; all of these wells were producers. Combined final open flow from 4 wells was 3,492 Mcf; one well was to be cleaned up and one well was to be fractured. Columbia Gas Transmission Corporation produced 1,125,400 Mcf to give Dickenson County a total production of 3,897,296 Mcf.

In Lee County oil production by Robert F. Spear totaled 1,742 barrels from 4 wells; 3 wells are located in the Rose Hill field and 1 well is in the Ben Hur field. Lee Oil Drilling Company drilled two wells in 1977. One development well in the Rose Hill field was drilled to a depth of 1,762 feet. The well was plugged and abandoned as a dry hole. The second test was a wildcat several miles northeast of the Rose Hill field; total depth was 7,209 feet and the well was plugged and abandoned.

In Russell County, Gulf Oil Corporation completed drilling an exploratory wildcat test north-northwest of Dickensonville to a total depth of 17,003 feet; the well was plugged and abandoned as a dry hole.

Two operators in Tazewell County produced 692,986 Mcf of gas; Columbia Gas Transmission Corporation, 263,539 Mcf, and Consol-Ray Resources, 429,447 Mcf.

Penn Virginia Corporation produced 5,192 Mcf of gas in Wise County for use in a coal preparation plant. Columbia Gas Transmission Corporation drilled one test in the county to a depth of 5,740 feet; this test was completed as a producing well.

MICRO—EARTHQUAKE MEASURING DEVICE INSTALLED

With a mutual interest in earthquake activity the Division of Mineral Resources is sharing its seismic facility with the Department of Geological Sciences of Virginia Polytechnic Institute and State University. They are monitoring microseisms — those of very low magnitude. This monitoring effort is a long range project to determine microseismic activity in central Virginia. Several such instruments are being installed. The College of William and Mary has set aside two acres of land near Charlottesville for the Division of Mineral Resources so that this activity could continue without interruption in future years in order that a continual monitoring program could be maintained.

Interior view of vault from which seismic activity is monitored. Instruments shown receive and amplify ground vibrations for transmission to recorders.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addressees)

Publication 3. GEOLOGY OF THE WAYNESBORO EAST AND WAYNESBORO WEST QUADRANGLES, VIRGINIA, by Thomas M. Gathright II, William S. Henika, and John L. Sullivan III; 53 p., 2 maps in color, 38 figs., 7 tables, 1977. Price $6.25 plus $0.25 State sales tax, total $6.50.

The rocks of the Blue Ridge anticlinorium are complexly folded and faulted and consist of five sequences ranging from Precambrian gneisses to Cambrian clastics. The Massanutten synclinorium within the study area is formed from the overlying Cambrian and Ordovician carbonate sequence. These carbonate rocks are overlain by the Ordovician clastic sequence. Many of these rock units are locally intruded by diabase dikes of Triassic age and are locally covered by alluvial Quaternary sediments.

The intensity of deformation increases from northwest to southeast with recumbent folds, thrust faults, and zones of cataclastic rocks present in the southeastern portion of the area.

Sources of agricultural limestone, limestone aggregate, and in limited quantities of high-calcium limestone are present. Ceramic clay, crushed stone, sand and gravel, and iron and manganese ore have been produced in small quantities.

Fourteen environmental geologic units having similar geologic factors—bedrock, residuum, and soil properties—affecting land modification have been delineated. Each is briefly evaluated with respect to slope stability, erodibility, and response to excavation or other types of land modification. Rockfall, karst, and cave areas have been delineated.

Publication 7. CONTRIBUTIONS TO VIRGINIA GEOLOGY—III. 154 p., 61 figs., 21 tables, 1978. Price $4.50 plus $0.18 State sales tax, total $4.68.

This publication is dedicated to Dr. James L. Calver, State Geologist, upon his retirement. Accomplishments of the Division under his leadership are discussed in "The Calver Years—1957-1978". Other articles include the following:

PRODUCTION OF MINERAL RESOURCES IN VIRGINIA by D. C. Levan

At present more than 30 different mineral resources are produced in Virginia. The value of mineral production in 1976 exceeded a billion dollars, of which mineral fuels contributed about 84 percent, nonmetallic minerals about 15 percent, and metallic ores slightly less than 1 percent. The principal mineral fuel commodity is bituminous coal. Nonmetallic resources produced include crushed and dimension stone, raw materials for cement and lime, sand and gravel, clay materials, kyanite, gypsum and anhydrite, feldspathic rock (Virginia aplite), silica sand, mineral pigments, talc and soapstone, marl, shells, and specimen and lapidary materials. Production of metallic ores is currently limited to mining of lead and zinc minerals at one locality. Summary information is given for the various commodities, including history, scope of activity, source of materials, uses, tables of tonnage and value where available, and selected references. Other resources that have been recovered in the past are outlined briefly.

GEOPHYSICAL CHARACTERISTICS OF THE BLUE RIDGE ANTICLINORIUM IN CENTRAL AND NORTHERN VIRGINIA by Stanley S. Johnson and Thomas M. Gathright, II

Evaluation of regional aeromagnetic, and simple Bouguer gravity maps and detailed gravity profiles of the Blue Ridge anticlinorium in central and northern Virginia provides greater insight into the structure and distribution of rock units depicted on existing geologic maps. Characteristic radioactivity and magnetic signatures of known rock units can be traced into adjacent areas and will aid future detailed geologic mapping of these areas. The geophysical data is used to interpret gradational relationships between the major metamorphosed plutonic rock units within the anticlinorium and to delineate smaller felsic intrusives. Aeroradiometric data provides insight into the location of cataclastic and sedimentary rock units that could possibly be overlooked in normal field mapping. Detailed gravity data provides valuable information on the near surface and deep structural features such as the large, low density rock body beneath overturned quartzite beds at the Shady-Antietam contact.

TOPOGRAPHIC MAPS OF VIRGINIA by Harry W. Webb, Jr.

Due to the completion of a cooperative Virginia Division of Mineral Resources—U. S. Geological Survey mapping program detailed 1:24,000—scale topographic maps are available for all of the Commonwealth. Maps of growth areas are being updated from inspection of aerial photography each 5 years. Maps are especially useful for engineers, foresters, geologists, planners and for recreation such as fishing, hiking, and hunting. By-products of the mapping program are aerial photographs and geodetic control. Four different scale series are available to show features of the State. These range in use from depiction of small areas in much detail to large areas with little detail. Map products are available for some parts of the State as orthophotoquads and as slope, county, orthophoto, and land-use maps.

ORDOVICIAN SHELF—TO—BASIN TRANSITION, SHENANDOAH VALLEY, VIRGINIA by Eugene K. Rader and William S. Henika

Detailed mapping and petrographic study of Ordovician carbonate and siliciclastic lithofacies in the Shenandoah Valley provide the data from which depositional units can be related. An Ordovician shelf—to—basin transition is recognized throughout the Shenandoah Valley. Areal and vertical distribution of lithofacies can be related to a gently subsiding carbonate platform that existed from Middle Cambrian through early Middle Ordovician time. In early Middle Ordovician time the platform began to collapse in isostatic response to rising tectonic highlands to the southeast. Collapse of the platform edge occurred earliest and most precipitously in rocks now exposed along the southeastern limb of the Massanutten synclinorium.

SAND AND GRAVEL RESOURCES IN VIRGINIA by Palmer C. Sweet

In Virginia more than one-third billion short tons of sand and gravel have been produced during the 20th century. Sand has been produced for use as an abrasive, building, paving, engine (traction), fill, filter, fire (furnace), foundry (molding) and glass sand and for ice control, golf courses, railroad ballast, pottery, and other industrial sands. Gravel resources have been produced for use in building, fill, paving, railroad ballast, and miscellaneous products.

Figures on the average cost of some sand and gravel products over the last 40 years as well as some requirements for concrete aggregate are provided. A graph depicts the quantity and value of sand and gravel resources produced by year. Some mention of specifications, governmental regulations and restrictions, and reclamation requirements that sand and gravel producers encounter is also made.

STREAM-SEDIMENT GEOCHEMISTRY OF THE IRISH CREEK TIN DISTRICT, ROCKBRIDGE COUNTY, VIRGINIA by Oliver M. Fordham, Jr.

Sediments of the Irish Creek tin deposits were analyzed for Be, Co, Cu, Fe, Mn, Ni, Pb, and Zn by atomic absorption, for Sn, Ti, and Zr by x-ray fluorescence, and for heavy-mineral percentage by heavy-liquid separation.

The concentration of Be, Ti, Fe, and heavy minerals in stream sediments were found to be useful as pathfinders. Statistical evaluation of Co, Cu, Mn, Ni, Pb, and Zn in the iron-manganese oxide coatings on the sediments proved these elements to be independent of the tin content and unrelated to tin mineralization.

X-ray fluorescence analysis is a precise and rapid technique for the determination of tin; the 4 ppm detection limit is sufficient to detect all known tin-bearing areas in the Irish Creek district. Tin and beryllium in the 80-230 mesh stream sediment fraction were found to be the best variables tested for outlining greisen containing tin mineralization. An area unrelated to previous mining activity or known tin veins was located that has anomalous tin and beryllium concentrations.

RARE-EARTH AND THORIUM MINERALIZATION IN SOUTHEASTERN RAPPAHANNOCK COUNTY, VIRGINIA by Christopher R. Halladay

An aeroradiometric contour map of a portion of southeastern Rappahannock County, Virginia shows several thorium anomalies. The main anomaly, located near Woodville, is related to occurrences of rare-earth and thorium mineralization. The proximity of the rare-earth-and thorium-bearing rocks to outcrops of alkali granite suggests the mineralization is related to alkaline magmatism in the late Precambrian.

GEOLOGY AND GEOPHYSICS OF WARREN COUNTY, VIRGINIA by Eugene K. Rader and Stanley S. Johnson

Detailed geologic and geophysical mapping in Warren County by the Division of Mineral Resources affords the opportunity to examine the correlation of geological and geophysical data in the Blue Ridge and Valley and Ridge physiographic provinces in the northern part of Virginia.

Along the west slope of the Blue Ridge the Catoctin and Pedlar formations and the Chilhowee Group are readily distinguishable by their characteristic magnetic pattern. Large greenstone intrusives are well defined by linear magnetic highs in the southern part of the county. Major faults are frequently shown as a series of aligned magnetic lows. Northeast of Front Royal the aligned magnetic lows are associated with a collapse breccia zone.

A north-northwestward-trending linear extends across Warren County from near Compton Peak through Buckton. It corresponds to the abrupt Bouguer gravity gradient change. The sinuous nature of the Front Royal Fault may be explained by late basement movement along the linear that warped the fault as part of a northeastward-facing monocline.

CORRELATION OF STREAM-SEDIMENT MINERALOGY WITH GEOLOGY, CENTRAL PIEDMONT OF VIRGINIA by Richard S. Good

Semiquantitative analysis of minerals in stream sediments in Fluvanna and western Goochland counties accurately reflects nearby bedrock geology in much of the area and is useful as an aid or supplement to geologic mapping.

Rapid analysis by X-ray diffraction and binocular microscope was made on samples already collected for regional trace-element studies. Comparisons of stream-sediment and soil mineralogy samples were indicative of a much greater abundance and freshness of unstable minerals in stream sediments compared to soils.

Microcline in large amounts (5 to 25 percent) was found to be associated with sediments derived from migmatite of the Hatcher complex, particularly in areas of younger plutons within the Hatcher and in areas of pegmatite. Mocrocline is strikingly absent (less that 2 percent) in the Columbia syncline. Amphibole (hornblende) comprises 3 to 15 percent of samples taken from streams draining Chopawamsic metavolcanic rocks and actinolite from some diorite intrusives. Epidote in amounts of 3 to 15 percent is characteristic of sediments derived from the Hatcher complex and is strikingly absent from the Arvonia and Columbia synclines and thus outlines them. The garnet-staurolite mica schist belt of the Columbia syncline is shown by both garnet and staurolite, and rocks of the Candler Formation are reflected in a broad zone of high mica stream sediments with statistically high lithium content.

GEOLOGY OF THE PIEDMONT OF VIRGINIA—INTERPRETATIONS AND PROBLEMS by James F. Conley

Virginia contains three areas of exposed Grenville-age basement—the Sauratown Mountains anticlinorium, the Blue Ridge anticlinorium, and the gneiss dome in Goochland County. Rocks of the Lynchburg, Catoctin, Candler, and Chopawamsic formations overlie the basement on the southeastern limb of the Blue Ridge anticlinorium. The Chopawamsic Formation is correlated with metavolcanic rocks to the southwest at Danville. Rocks of the Carolina slate belt are suggested to conformably overlie these metavolcanic rocks. The Quantico and Arvonia synclines contain rocks that are tentatively correlated with each other and are believed to unconformably overlie the Chopawamsic Formation. The Quantico syncline is thought to be folded aroung the northwest limb and nose of the later-formed Columbia synform. With increasing metamorphic grade to the southeast, rocks of the Chopawamsic Formation grade into the Hatcher complex. The discovery of billion-year-old felsic gneiss in an antiformal structure in Goochland County is evidence that continental crust underlies this sequence of rocks and makes questionable a suture zone in the Piedmont of Virginia.

ADDITIONS TO STAFF

Mr. David A. Hubbard, Jr. was employed by the Division on January 16, 1978 and will assist with geologic mapping studies in the Coastal Plain area of the State. He earned his B.A. in geology from the University of Virginia, Charlottesville, Virginia in 1973 and later pursued environmental work to receive his M.S. from the same school in 1977. He has worked with recent sediments and maintains an interest in developing applications of geologic information related to land-modification planning and development.

Mr. Peter S. Frischmann joined the Division staff on March 16, 1978 and has been assigned to the western mapping section. He is engaged in geologic investigation supportive to development of sequential land use of the State. Mr. Frischmann received his B.A. in geology from Lafayette College, Easton, Pennsylvania in 1974 and his M.A. in geology from Temple University, Philadelphia, Pennsylvania in 1978.

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PUZZLE ANSWERS

Did you find all these important mineral resources as shown on page 22 in the puzzle?

Amphibolite	Gravel	Petroleum
Anhydrite	Granite	Quartzite
Aplite	Gypsum	Sand
Basalt	Iron	Shale
Clay	Kyanite	Silver
Coal	Lead	Slate
Diabase	Lime	Soapstone
Dolomite	Marl	Talc
Feldspar	Natural Gas	Zinc
Gems	Oyster Shells	

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NATURAL HERITAGE DAY

Sunday, June 18, 1978, was designated as Natural Heritage Day by Governor John N. Dalton on behalf of the Virginia Department of Conservation and Economic Development. According to Mr. Fred Walker, Department Director, this was an opportunity for Virginians to consider and observe the State's natural heritage, particularly the industrial jobs and products that benefit from it. The economic well-being of Virginia's citizens can co-exist with protection of the environment. At many facilities of the Department's Divisions special events were held to emphasize the importance of the Day.

VIRGINIA GEOLOGY FIELD CONFERENCE

On October 14-15, 1978, the Tenth Annual Field Conference will be conducted by Wayne Newell and Robert Mixon, U. S. Geological Survey about the fault-controlled Coastal Plain margin at Fredericksburg, Virginia. Conference trips, where geological features are discussed in the field, are open to all interested in the geology of Virginia. For information contact Bruce Goodwin, Department of Geology, College of William and Mary, Williamsburg, VA. 23185.

Organized in 1968 by members of the Geology Section, Virginia Academy of Science, the Field Conference was established to provide annual fall field trips, on which anyone interested in the geology of Virginia would have the opportunity to view and discuss geological features in the field. The trips brought together and helped establish communication and fellowship between geologically oriented persons from such diverse groups such as colleges, industry, State and Federal geological surveys, earth science teachers, soil scientists, and rock and mineral collectors. Guidebooks are written for the trips; these can also be used for other groups or individuals to retrace the routes and study the geology. For availability of past guidebooks contact Bruce Goodwin at address listed above. The only officer is a Secretary, elected for an indefinite length of time by the members of the Geology Section, Virginia Academy of Science.

The first trip of the Field Conference was held in Williamsburg in the Fall of 1969 with about 80 participants and a great deal of optimism and enthusiasm. Since then annual trips have been held in the areas of Lexington, Charlottesville [illegible]n, Martinsville, Richmond, Big Stone [illegible], [illegible] Royal and Harrisonburg. All the physiographic provinces of the Commonwealth have been visited at least once. Some years over 150 people have attended. At the 1978 spring meeting of the Geology Section, Virginia Academy of Science, the members voted to establish an award of $50 each year to the student who presents the best paper at the section annual meeting.

The broad support for the Field Conference is indicated by the diversity of trip leaders. Of the nine field trips, five have been organized by college faculty, two by staff of the Virginia Division of Mineral Resources, and two by members of the United States Geological Survey.

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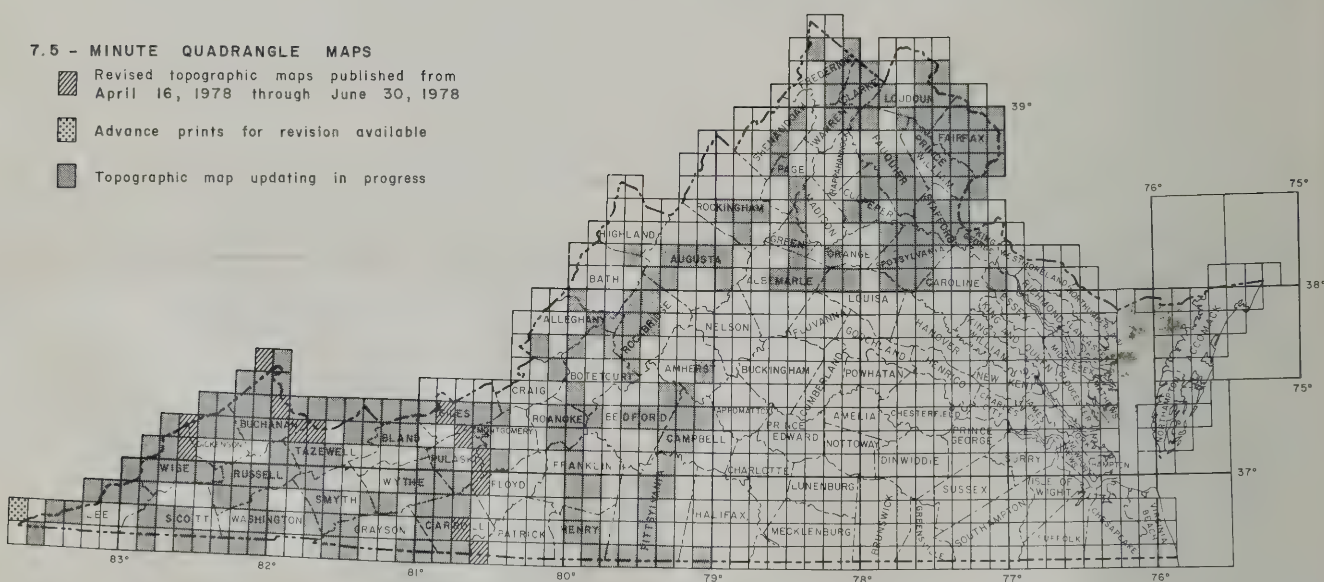
TOPOGRAPHIC MAPS



Revised 7.5-minute quadrangle maps published from April 16 through June 30, 1978:

Revised Maps

Amonate	Jewell Ridge	Patterson
Fancy Gap	Majestic	Pound
Indian Valley	Mt. Airy North	Radford South
Jenkins East	Narrows	Staffordsville

ADVANCE PRINTS

Advance prints are available at $1.25 each from the Eastern Mapping Center, Topographic Division, U.S. Geological Survey, Reston, Virginia 22902.

Advance Prints for Revision Middlesboro North

PUBLISHED TOPOGRAPHIC MAPS

Total State coverage completed; index is available free. Updated photorevised maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published maps for all of Virginia are available at $1.25 each (plus 4 percent State sales tax for Virginia residents) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903.

VIRGINIA MINERALS

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SEISMIC HAZARD IN VIRGINIA

G. A. Bollinger[1]

With respect to its sister states, Virginia has an intermediate level of earthquake risk. It is not as aseismic as South Dakota or as seismically active as California. Virginia has experienced moderate (magnitude $\leq$ 5.8) earthquakes within her borders in the historic past as well as being affected by larger earthquakes centered in South Carolina (magnitude = 6.6-6.9) and in Missouri (magnitude $\leq$ 7.3). The State's earthquake activity during the past several decades has been low but persistent. During the current decade (1968-78), Virginia residents have felt the vibrations from 15 small (magnitude $\leq$ 3.5) shocks. This continuing seismic activity, plus the record from the past, indicates the need for both preparedness and surveillance.

MEASURES OF EARTHQUAKE SIZE

To consider earthquake history and seismic risk, it is necessary to understand the two measures of earthquake size—magnitude and intensity. The former is well-known and often called the "Richter magnitude" after the California Institute of Technology professor that developed the scale. It is a quantitative measure of the energy released as seismic waves by an earthquake. Because it contains a distance-correction term, determinations at different observatories should, within experimental error, be the same for a given earthquake. There is *only one magnitude number associated with each shock*. The magnitude scale is logarithmic and thus each increase of one unit corresponds to a tenfold increase in ground vibration amplitudes. In a very approximate manner, damage is slight at the 4.5 magnitude level, becomes moderate at the 5.5 level, and from 6.5 up can be considerable to great.

The intensity measure of earthquake size is qualitative and intended to specify the severity of the earthquake motion at a given point by its effect on people, structures and the landscape at that point. It will be largest near the epicenter and decrease with distance away from that location. Thus, there are *several intensity numbers associated with each shock*. As a general rule only the maximum of these is listed in earthquake catalogs. A typical application of intensity data is to plot the values for a given earthquake at their appropriate locations on a map and then to contour these values. The resulting map, that depicts the areas which experienced the same levels of shaking, is termed an isoseismal map or an intensity map.

The intensity scale used in the United States is called the Modified Mercalli Scale and has 12 degrees, ranging from I (felt by only a few people under especially favorable circumstances) to XII (total damage). By convention, Roman numerals are used to denote intensity and Arabic numbers for magnitude. Damage begins at about the intensity VI level. Table 1 contains a listing of the intensity VI-X effects and has the estimated magnitude range expected for each of those levels.

[1]Department of Geological Sciences and the Extension Division, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

Table 1. Modified Mercalli Scale, intensities VI through X.

Intensity	Description of Effects	Magnitude
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.5-5.0
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving automobiles.	5.0-5.7
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, some partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving automobiles disturbed.	5.7-6.3
IX	General panic. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, some partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	6.5+
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water thrown over banks on canals, rivers, etc. Serious damage to dams, dikes, and embankments.	

Currently magnitude and intensity are determined for each earthquake. However, prior to the 1950's there were too few seismographs in the eastern United States to make magnitude calculations. Thus, most of the historical data base consists of only intensity data. Modern data has been used, however, to infer magnitudes for the older shocks.

EARTHQUAKE HISTORY OF VIRGINIA

During the period 1774-1970, some 128 Virginia earthquakes have been cataloged (Bollinger, 1975). A thorough search of archival data sources (journals, diaries, newspapers, etc.) resulted in a detailed listing of the effects at specific Virginia localities for 100 of those shocks (Hopper and Bollinger, 1971; Bollinger and Hopper, 1972). The largest earthquake known to have occurred in Virginia was in Giles County on

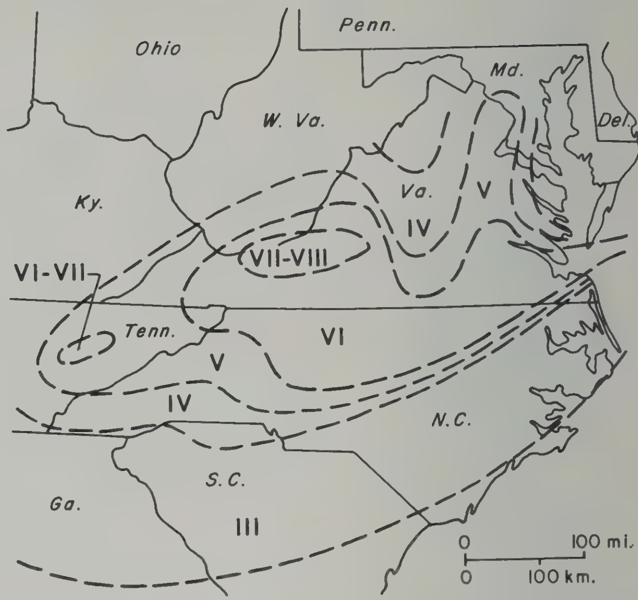

Figure 1. Isoseismal map for the Giles, County, Virginia earthquake of May 31, 1897.

May 31, 1897. That shock was felt in portions of 12 states over an area of at least 280,000 square miles (Hopper and Bollinger, 1971, 1972; Figure 1). Its maximum intensity was VIII and the magnitude has recently been estimated to have been 5.8 (Nuttli, Bollinger and Griffiths). Effects in the epicentral area (Pearisburg) were structural damage to some brick buildings, rock slides and landslides (in one instance derailing a freight train) and muddying of springs and creeks. There was considerable fright among the people of the region but no reported injuries or deaths. Hundreds of people in Richmond and Norfolk left their homes in alarm.

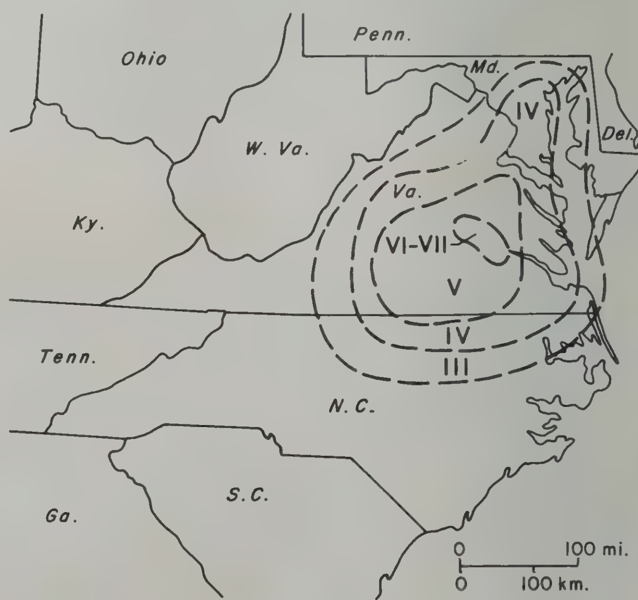

Figure 2. Isoseismal map for the Chesterfield County, Virginia earthquake of December 22, 1875.

The second largest earthquake in Virginia was on December 22, 1875 in Chesterfield County (Hopper and Bollinger, 1971, 1972; Figure 2). It was felt over 50,000 square miles and had an intensity of VII and an estimated magnitude of 5.0 (Nuttli, Bollinger and Griffiths). Effects noted were trembling of large buildings, awakening and frightening many people, broken windows, chimney and plaster damage and waves at the James River Dock that caused several craft to part their cables and drift down stream from the wharf.

The most recent earthquake to cause damage in Virginia was on November 19, 1969, and centered just across the State line at Glen Lyn near Elgood, a small West Virginia community (Bollinger and Hopper, 1970; von Hake and Cloud, 1969). Its magnitude was 4.6 and the felt area was 125,000 square miles (Figure 3). The effects in Glen Lyn were: many windows,

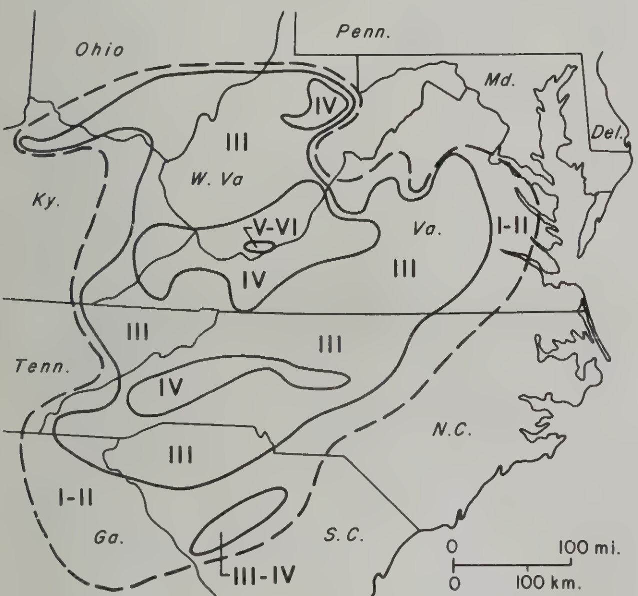

Figure 3. Isoseismal map for the Elgood, West Virginia earthquake of November 20, 1969.

including display windows, were broken, cracked and fallen plaster and a large boulder rolled onto the railroad tracks. The foreman on duty at the Glen Lyn Power Plant reported that, had the vibrations continued for another several seconds, he would have shut the generators off.

SEISMIC ZONES IN VIRGINIA

Study of the historical data base plus seismographic investigations of recent shocks has led the writer to the delineation of three seismic zones in which the majority of the earthquakes have occurred in Virginia (Bollinger, 1973; Figure 4). Faults associated with the earthquakes are thought to occur at depths of three to ten miles and their association, if any, with the faults mapped by geologists on the surface, is unknown in

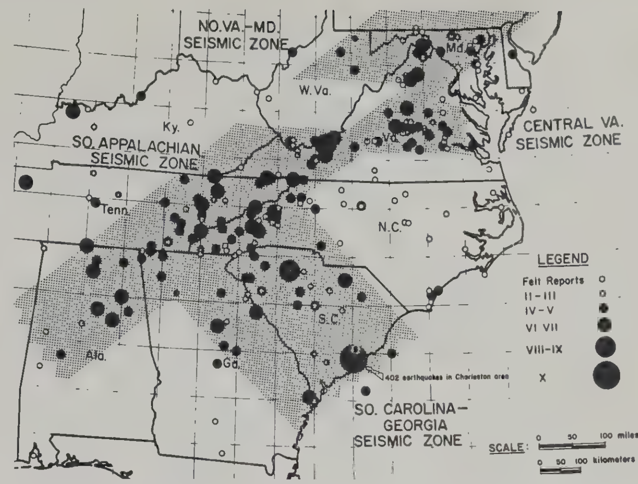

Figure 4. Southern Appalachian seismicity, 1754-1970. Delineation of seismic zones in the southeastern United States.

Virginia or, for that matter, in the eastern United States. These zones have been named: the central Virginia seismic zone, the northern Virginia-Maryland seismic zone and the southern Appalachian seismic zone and are located where earthquake occurrence is most expected. However, the effects from out-of-state earthquakes must also be considered in any

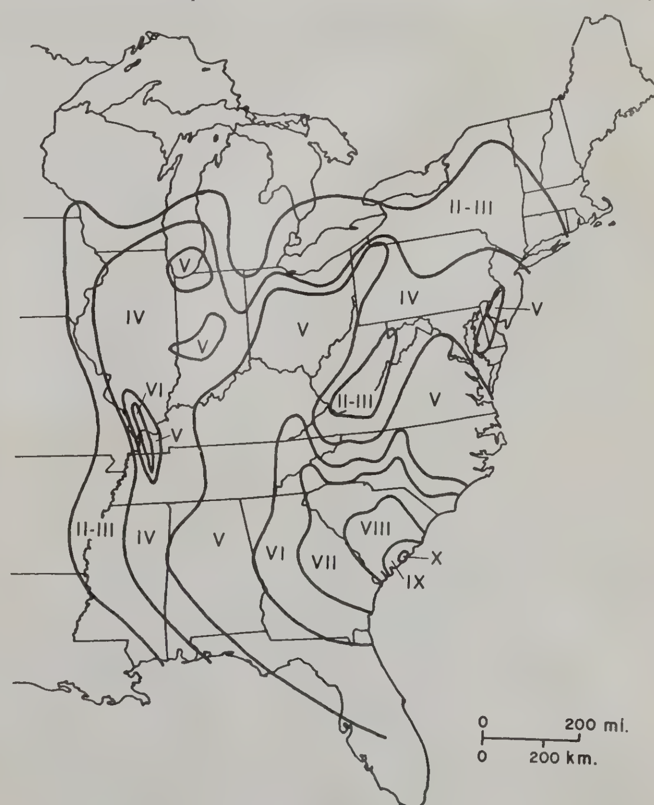

Figure 5. Isoseismal map of the eastern United States contoured to show the broad regional patterns of the reported intensities for the 1886 Charleston earthquake.

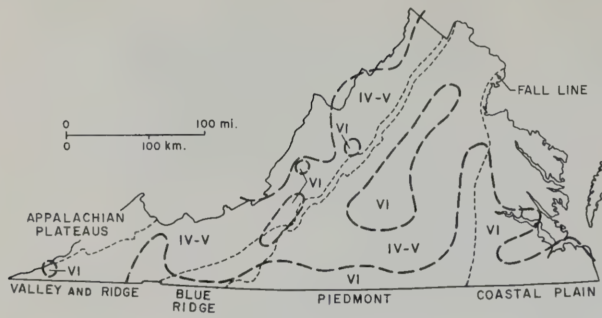

Figure 6. Isoseismal map for the effects in Virginia from the 1886 Charleston earthquake.

risk evaluation. The two major examples of this type of situation are the 1886 Charleston, South Carolina earthquake and the 1811-12 New Madrid, Missouri earthquakes.

The 1886 Charleston, South Carolina earthquake is the largest event known to have occurred in the southeastern United States. It was felt over two million square miles, caused five million dollars damage (1886 dollars) and approximately 60 deaths (1886 population density) (Bollinger, 1972; Figure 5). The maximum intensity was X and the magnitude has been estimated between 6.6 and 6.9 (Nuttli, Bollinger, Griffiths). The areas reportedly affected in Virginia are shown in Figure 6 (Ayers and Bollinger, 1975). The more severe of these are listed (Table 2). These accounts indicate that widespread alarm and minor damage resulted in Virginia from an earthquake centered some 300 miles to the south. Figure 6 also shows that there are two regions in the State—the Coastal Plain-Piedmont boundary (Fall Line) and the Piedmont-Blue Ridge boundary—where exaggerated or amplified vibrational effects can occur. This particular aspect, special ground conditions, will be discussed in a later section.

Table 2.—Effects of the Charleston earthquake of 1886 in Virginia.

Locality	Effects
Culpeper	Chimneys thrown down
South Boston	Chimneys thrown down
Henrico County	Difficult to remain standing
Richmond	Population in the streets; chimneys knocked down; prisoners rioted in cells at penitentiary, militia and police called out to restore order; pictures and plaster fell from walls; many residents felt nausea caused by the vibrations; people thrown from their feet
Abingdon	Plaster shaken down
Chesterfield County	Chimney and plaster damage
Danville	Chimney damage; walls cracked
Farmville	Plaster and chimney damage
Lee County	Plaster and chimney damage; broken windowpanes
Lynchburg	Chimney damage
Norfolk	Chimneys broken; light framework thrown down; large warehouses damaged; panic at Opera House; many people nauseated
Petersburg	Windowpanes broken
Patrick County	Bricks thrown from courthouse
Surry County	Plaster damage
Williamsburg	Plaster damage

The Mississippi Valley earthquakes (vicinity of New Madrid, Missouri) of 1811 and 1812 rank as the largest to have occurred in North America since its settlement. There were three principal shocks, each with intensities up to XI and magnitudes greater than 7, that were felt over two million square miles (Nuttli, 1973a). Because of the sparseness of the population at that time, the effects of these great earthquakes are not as well documented as those for the 1886 South Carolina shock. However, reports from Richmond newspapers indicated that the events were distinctly felt throughout the city, "most sensibly felt on the hill." Many people ran from their houses in alarm and bells were set ringing. These reports, plus Nuttli's study, again emphasize the large distances to which earthquake effects can extend.

Table 3.—Earthquake cyclicity.

Maximum Intensity	Number Expected Per 100 Years	Recurrence Rate (Yrs)	Years Since Last Occurrence
V	115	0.9	0
VI	30	3.4	2
VII	8	13	62
VIII	2	51	65
(IX, X)	(0.5, 0.1)	(200, 780)	92

EARTHQUAKE FREQUENCY IN VIRGINIA

It is well-known that large earthquakes occur less frequently in Virginia than in California. A question that logically follows is: what is the frequency of occurrence of a certain magnitude earthquake at a certain place? Studies of the recurrence rates of earthquakes assume that the geological process leading to their occurrence are stable enough to give a cyclical pattern. This assumption appears to be valid in regions of high seismicity, but in regions such as Virginia it is an unverifiable assumption. There have been too few large events to establish their recurrence rate (if there is one). Fortunately in this regard such bad experiences have not occurred but without them it would be difficult to specify when the next one will happen. An analogy here is: given the precipitation amount for one month, predict the annual rainfall.

On the assumption that cyclicity can be applied to the two centuries of data compiled for the southeastern United States (the data for Virginia alone are too sparse to permit this type of analysis), frequencies and recurrence rates may be calculated as shown in Table 3 (Bollinger, 1973). The values in parentheses are extrapolated values. These data indicate that either the region (southeastern United States) is overdue for

the occurrence of a damaging shock (intensity = VII or VIII) or that there is a change toward a lower level of activity. The problem of possible secular change (increasing or decreasing) in the seismicity of the southeastern United States remains unresolved.

EFFECTS OF NEAR SURFACE CONDITIONS

It is well-known to seismologists and earthquake engineers that earthquake intensities are greater on alluvium (deposits from rivers, streams, etc. such as are found on flood plains) than on hard rock sites for the same earthquake at the same distance. A soft surficial layer (soil, sand, alluvium, etc.) can, as a rule of thumb, increase ground displacements by a factor of 4 to 5 and accelerations by about 1 to 1.5 (Nuttli, 1973b). This response to vibration causes a variety of instability effects: 1. liquefaction of saturated sands and of thin sand layers with the resultant loss of bearing strength; 2. landslides; 3. fissuring and slumping on slopes and along river and stream banks; 4. settlement of cohesionless soils; and 5. sand craters and mud spouts.

While it is possible for these effects to occur at the lower intensity levels (VI-VII), they usually begin at the VIII level (Table 1). For example, they were present to only a small extent in the intensity VIII, 1897 Giles County earthquake, but this could be because of the absence there of large areas of soft surface layers.

A pronounced example of this class of effects, where the surficial layers are loosely-consolidated sands with a high water table, was the Charleston, South Carolina area after the 1886 shock. That locale experienced more than 50 miles of damaged railroad track (in one case derailing a train) and 500 square miles of extensive development of craters (with depressions up to 20 feet in diameter) and fissures. Additionally, in the city of Charleston, much of which is on made-land, most of the buildings were destroyed or seriously damaged.

Because of the similarity between the Coastal Plain in South Carolina and Virginia, the 1886 earthquake effects in the former can serve as a model for the latter. In addition, South Carolina does not have the pronounced estuary system as does the Virginia coastline. These narrow waterways can respond to earth motion with large wave action. As noted earlier, the intensity VII, 1875 earthquake did cause waves such that several craft parted their cables. Consideration of the foregoing factors plus the historical data base suggests that the region in Virginia most susceptible to this class of physical surface condition effects is the entire Coastal Plain.

The vertical configuration of the Coastal Plain sedimentary rocks is that of a wedge which has a featheredge at the Fall Line and thickens to thousands of feet at the coastline. These soft sediments overlie a hard rock basement that is exposed in the Piedmont to the west. Thus, there is a soft, wedge-shaped layer overlying a much more rigid sublayer. Such a situation can cause channeling of the vibrations within the wedge with resultant amplification at the thin wedge-edge. This effect in the Coastal Plain of Virginia is seen in the intensity patterns of the 1875 earthquake (Figure 2).

Earthquake vibrations can have a pronounced effect on the earth's surface or near surface layers. The most obvious of these are rock slides and landslides. The resulting damage to structures on a valley floor and/or damming of streams (sometimes with subsequent failure and flooding) is well-known. In Virginia, the Valley and Ridge and Blue Ridge provinces contain many areas susceptible to this type of effect (Sorensen and others, 1975). A minor amount of sliding did occur in the Giles County earthquake as a result of the 1897 event.

Another geometric effect is topographic amplification. Both theory and observation show that mountains and ridges can enhance ground vibrations by a factor of two to three times. What occurs is a "tuning" or "resonance" effect when the wavelength of the incoming seismic waves approximates the distance or "wavelength" between ridges. Although there are few structures built on ridge crests in Virginia, it is possible that existing high-voltage line towers might be affected.

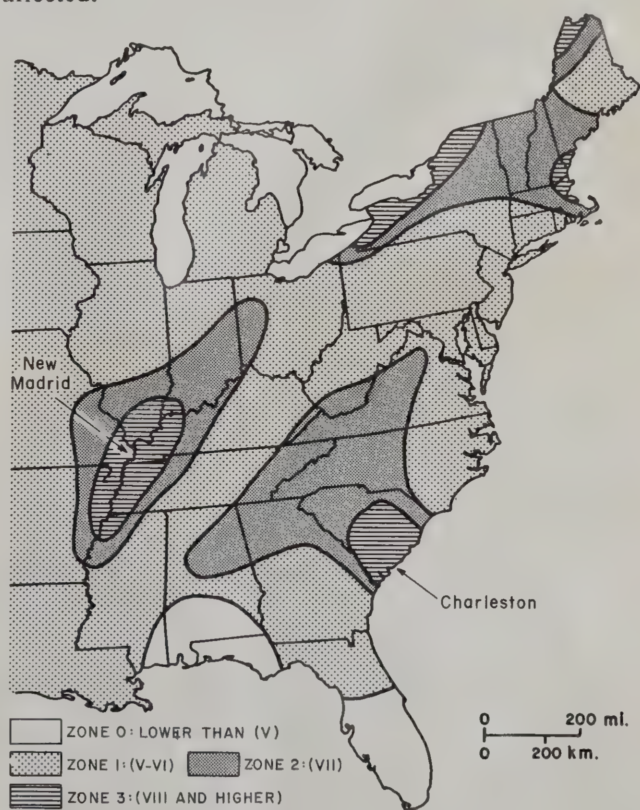

Figure 7. Deterministic seismic risk map for the eastern United States (after Algermissen, 1969).

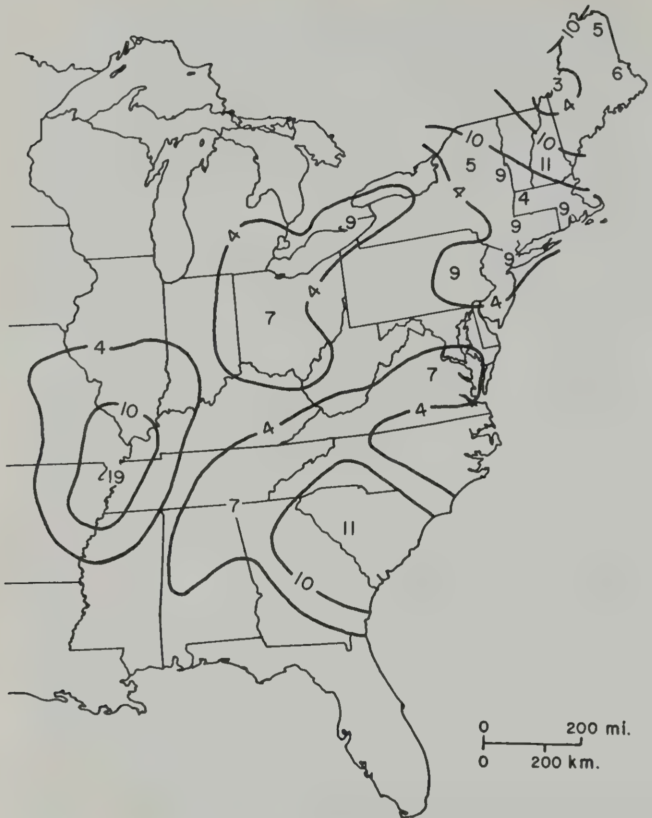

Figure 8. Probabilistic seismic risk map for the eastern United States (after Algermissen and Perkins, 1976). *Numbers* represent the horizontal acceleration level expressed in percent of gravity which has a 90 percent probability of not being exceeded in 50 years.

PREDICTED LEVELS OF GROUND SHAKING

The U. S. Coast and Geodetic Survey (Algermissen, 1969) issued a seismic [illegible]k map of the United States (Figure 7). T' [illegible] deterministic in that it was based primarily on the known distribution of historic, damaging earthquakes and their probable frequency of occurrence was not considered. In 1970 it was incorporated into the Uniform Building Code, the authoritative construction guide of the building industry. Two thirds of Virginia was classified at a zone 2 level that corresponds with intensity VII—moderate damage.

In 1976 the U. S. Geological Survey published a probabilistic risk map of the United States (Algermissen and Perkins, 1976; Figure 8). Extreme values of ground acceleration in the country range from 60% of gravity in California to less than 4% of gravity for most of the Great Plains. For Virginia, a maximum horizontal acceleration in hard rock of 7% of gravity was predicted to have a 90% probability of not being exceeded in 50 years. That level of acceleration would correspond to an intensity of VI (Murphy and O'Brien, 1977). Allowing one intensity unit higher for soft surficial sediments would bring the level to VII, the same as the 1969 Risk Map.

Thus, the two most comprehensive seismic risk studies for the country as a whole, plus the earthquake frequency analysis (Table 3), indicate that an intensity VII level of shaking—damage slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; chimneys broken; everyone runs outdoors—is possible in Virginia. Very poor ground conditions could easily increase these effects locally. Time of day would also be an important factor—children in school, people at work, etc.

Recently, McGuire (1977) has shown that intensities VIII to IX have an annual probability of 1 in 10,000 of being equaled or exceeded along the East Coast. His study included two sites in Virginia, but he did not consider the probability of occurrence of events at lower intensity levels

SEISMIC SURVEILLANCE IN VIRGINIA

The current seismic monitoring programs at Virginia Polytechnic Institute and State University (VPI & SU) and at the Division of Mineral Resources, Virginia Department of Conservation and Economic Development, will actually constitute seismic surveillance of the State. This surveillance is especially important to disaster mitigation in that the possibility for an "early warning" thereby exists.

In addition to the Worldwide Standard Seismograph Observatory already at Blacksburg, a recent Nuclear Regulatory Commission contract to VPI and SU is making possible the installation of a 10-station seismic network—five in Giles County and five in central Virginia. This network should be completely operational by the end of the year. Also, Virginia Ele[illegible] and Power Company has dona[illegible] Anna Power Plant (Louisa County) seismic stations and four of its Bath County Pumped Storage project seismic stations to VPI & SU. The data from all 18 of these seismographs will be carried to the Blacksburg campus for recording and analysis by telephone circuits.

The Division of Mineral Resources operates a short-period three-component seismograph system on a daily basis and as such contributes into the State's seismic network. An article describing this operation and data generated therefrom was published in the February issue of *Virginia Minerals* (Lasch, 1977). Both Virginia Polytechnic Institute and State University and the Division of Mineral Resources have worked cooperatively on seismic monitoring—this collective State network should allow excellent surveillance of the Commonwealth.

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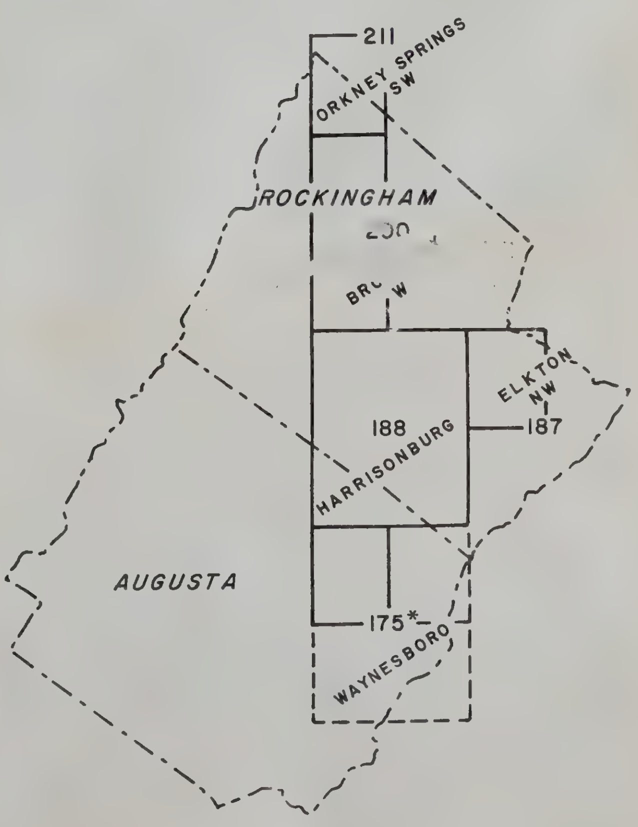
RADIOMETRIC MAPS—NORTHWESTERN VIRGINIA

An aeroradioactivity survey that covers 510 square miles in parts of Rockingham and Augusta counties has been released by the Virginia Division of Mineral Resources. This extends from Bergton southward through Harrisonburg to Ft. Defiance. Information is illustrated on five separate maps at a scale of 1:62,500.

This geophysical survey adjoins similar surveys obtained in 1975 and 1976 of the area approximately b[illegible] by Appomattox, Rappahannock and Powhatan cou[illegible] at 500 feet above terrain in an east-west direction with flight lines one-half mile apart. A gamma-ray spectrometer was utilized to record the total counts per second as well as the individual responses of potassium, thorium and uranium. Radiometric maps are useful in the mapping of rock types, especially where they are covered by soil, and in the location of possible uranium occurences.

Order maps by 15-minute area name (see illustration; *map includes Waynesboro City area from 1976 radiometric survey). These are available as ozalid copies for $5.20 (includes $0.20 State sales tax) each from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA. 22903. An ozalid composite copy of the total survey at the scale of 1:250,000 is available for $10.40 (includes $0.40 States sales tax); an unfolded mylar copy is available for $15.60 (includes $0.60 State sales tax).



POTHOLES

Bruce K. Goodwin[1]

Massive exposures of the Petersburg granite occur in the bed of the James River at Richmond. Some of the dominant surficial features are the many circular depressions which have been scoured into the solid rock by the turbulent action of the river. These depressions, called potholes, are ground out from the bedrock of stream beds by the abrasive action of coarse sand, pebbles, cobbles, or boulders which are swirled around and kept in motion by eddies or the force of the stream's current in a given spot. Once a small pothole develops, the depression tends to accumulate coarse sediments and to be subjected to intensified whirling action of currents. Through this continued localized abrasion they tend to increase in depth and diameter with time.

Numerous potholes have developed in the bed of the James River between Belle Isle and the river's south bank west of the Robert E. Lee Bridge, Figure 1.

Figure 1. Numerous rounded potholes developed in the Petersburg granite.

The river flows around the island in two channels. A dam between the north end of Belle Isle and the south bank of the river has diverted the main flow of the stream into the north channel. As a consequence, during low flow stages little water enters the stream bed south of Belle Isle and a broad expanse of granite bedrock is exposed. At times of normal flow many of these exposures are covered by turbulent water and during flood stages the James River has risen to over twenty-six feet above its normal surface at Richmond. A railroad bridge formerly connecting the east end of Belle Isle to the south bank of the river was partially demolished by the severe floods of 1972 and bears testimony to the violent force of the James River during times of flood.

The large exposures in the bed of the river are accessible from the eastern parking lot of the James River Park, which is a short distance upstream from the south end of the Robert E. Lee Bridge at the junction of Riverside Drive and 22nd Street. From the granite steps at the northeastern corner of the parking lot cross over the railroad tracks on the Park footbridge. From the overlook at the north end of the bridge is a beautiful panoramic view of the James River Valley and the Fall Zone of the James. This zone has rapids and small waterfalls that mark the nead of navigation in the river. Granitic rocks of the Piedmont occur upriver to the west and sediments of the Coastal Plain, downriver to the east. These sediments have easily been eroded by the river while the granite has resisted erosion thus creating the falls of the James. Descend the steps and follow the rocky path east along the river to a concrete walkway which will lead to a broad, flat exposure of granite.

A few potholes occur on this broad exposure and hundreds more are "carved" into the surface of the granite between the river's south bank, Belle Isle, and the dam. Arcuate remnants of potholes which have been partially eroded away are prominent on many of the near vertical granite faces where the stream has cut along joint planes. They vary in diameter from a few inches to over five feet and some are five feet deep. The bottoms of the potholes are usually covered with well-rounded sand, pebbles, and cobbles. These gravels are composed dominantly of resistant materials such as quartzite and vein quartz; rock types from as far away as the Blue Ridge are present. Some potholes are circular and many are elliptical; in a few, the granite was abraded so that the potholes are wider at the bottom than at the t[illegible] At least two potholes, both adjacent to [illegible]lle Isle, h[illegible] through [illegible]hanging ledges [illegible] cl[illegible] tunnels in the granite.

Pothole development may be a major process by which some streams deepen their channels. It appears that the inception and growth of potholes has been a dominant factor in aiding the James River in cutting and deepening its channel through the granitic bedrock. Their locations have been determined by inherent characteristics of the rock on which they have formed. The Petersburg granite in some of these exposures is highly foliated and contains broad bands of differing composition and texture. It is cut by aplite, mafic, and pegmatite dikes and locally contains an abundance of xenoliths. These xenoliths are fragments of host rocks which were broken off during magma intrusion and are now preserved as inclusions within

[1]Bruce K. Goodwin, Department of Geology, College of William and Mary, Williamsburg, Virginia.

Figure 2. Debris filled pothole at intersection of two joints.

the granite. Numerous joints and some small faults with slight displacement cut the granite as straight, steeply inclined fractures. Two dominant joint sets intersect at an angle of about sixty degrees.

Joints and minor faults have been the chief factor in causing the localization of potholes. Many elliptical potholes are located on and parallel to joints. On this broad flat exposure is an excellent example of a small elliptical pothole developed along a minor fault. Along joints at the rock surface, mechanical weathering and stream erosion rapidly create slight surficial irregularities which cause the water's currents to eddy and swirl. Fragments are localized in these eddies and their abrasive action in a small area initiates a pothole. Joint intersections have also been favorable sites for pothole development, Figure 2. Here complete transiti[illegible]ed from small potholes just [illegible]s to large elliptical pothol[illegible] in a series along prominent join[illegible]re are deep joint-controlled channels with large crescent shaped pothole remnants on their sides, where much of the original enclosing rock has been eroded away.

Changes in lithology have also served to localize pothole development. Where two types or textures of rock are in contact, differential weathering and erosion have also produced irregularities in the surface of the exposure. If a small xenolith or thin mafic dike occurs it has usually been more deeply eroded than the surrounding granite and potholes have frequently developed directly on the softer rock. Major compositional and textural contrasts occur along the margins of felsic and mafic dikes, xenoliths, and foliation planes within the granite.

The potholes in the bed of the James River are dynamic illustrations of the erosive power of a turbulent stream where its transported sediments have scoured into solid granite. This surficial process is often strongly controlled by structural and lithologic characteristics of the bedrock. The development of potholes has been a dominant process by which the James River has incised its path through granite.

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NEW AERIAL MAPPING PHOTOGRAPHY

High-altitude, quad-centered black and white aerial photography, taken 1978 is now available for revision inspection sector 2. The series of overlapping 9-inch by 9-inch prints can be used for stereo studies and for comparison with the corresponding 1:24,000 scale topographic map areas they portray. This sector includes that part of Virginia east of 77° west longitude and that area south of 37° north latitude between 77° and 78° west longitude (see reference map on page 12). The cities of Chesapeake, Emporia, Franklin, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Virginia Beach and Williamsburg are shown. By comparing this coverage with similar photography taken 1973 changes in physical and cultural features can be interpreted. Photographic reproductions of prints and enlargements can be obtained *only* from the National Cartographic Information Center-East, Mail Stop 536, U. S. Geological Survey, Reston, VA. 22092.

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ADDITION TO STAFF

Mr. Gilpin R. Robinson joined the Division staff on July 16, 1978 and is engaged in geologic mapping activities in the Piedmont. He received his B.S. in geology from Tufts University, Medford, Massachusetts and M.A. in geology from Harvard University. Mr. Robinson was previously employed with the U. S. Geological Survey in Reston, Virginia.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addresses)

Publication 1. BIBLIOGRAPHY OF VIRGINIA GEOLOGY AND MINERAL RESOURCES 1960-1969, by F. B. Hoffer, 68 p., 1977. Price $2.34 ($2.25 plus $0.09 State sales tax.)

Some 1300 references to published research, unpublished theses from U. S. colleges and universities, and Federal and State open-file reports on the Commonwealth's geology and mineral resources, are available as Publication 1. This 68-page bibliography has two listings, one by subject, county and city and the other by author. The publication was compiled by the Division librarian for the period 1960-1969.

Similar bibliographic listings are available for the years 1941-1949 (Information Circular 14—$0.52) and 1950-1959 (Information Circular 19—$1.30). Note that the Division's new Publication series replaces the former bulletins, reports, and information circulars.

Publications 8-13 are geologic studies of quadrangle areas. Rock type, structure and distribution are shown in color on topographic map bases. Origin and geomorphic expression of the units are described. Geologic and economic factors affecting man's modification of the land are discussed.

Publication 8. GEOLOGY OF THE NORFOLK NORTH QUADRANGLE, VIRGINIA, by W. J. Barker and E. D. Bjorken; geol. map (1:24,000) with map text, one sheet, 1978. Price $3.12 ($3.00 plus $0.12 State sales tax).

This quadrangle depicts the western portion of Norfolk City and the adjoining part of the City of Portsmouth in southeastern Virginia. Unconsolidated and semiconsolidated sediments exposed at the surface comprise the Sand Bridge and Tabb formations of Pleistocene age. Older Pleistocene age sediments (Norfolk Formation) and Pliocene age sediments (Yorktown Formation) occur in the subsurface. Structural configuration of the top of the Yorktown Formation is indicative that the present river systems reflect Pleistocene drainages. Four prominent geomorphic features are present, Willoughby spit; Diamond Springs scarp; Hampton flat; and Deep Creek swale.

Geologic units shown on the map are discussed in terms of potential use, permeability, slope stability, aquifer recharge, erosion resistance, and plasticity/sensitivity. Flood-prone areas are designated as those below 10 feet (3 m) elevation and which may be initially affected during extreme high water before run off or subsidence takes place. General load bearing capacities are depicted on the map. Extensive areas of fill are indicated along the Elizabeth and Lafayette rivers which outline the shoreline change between 1887 and 1973. Sources of sand are discussed.

Publication 9. GEOLOGY OF THE NORFOLK SOUTH QUADRANGLE, VIRGINIA, by W. J. Barker and E. D. Bjorken; geol. map (1:24,000) with map text, one sheet, 1978. Price $3.12 ($3.00 plus $0.12 State sales tax).

The Norfolk South quadrangle depicts the eastern part of Portsmouth City and adjacent areas of the cities of Chesapeake and Norfolk in southeastern Virginia. Unconsolidated and semiconsolidated sediments exposed at the surface are mapped as the Sand Bridge and Norfolk formations of Pleistocene age. Pliocene age sediments (Yorktown Formation) occur in the subsurface. Structural configuration of the top of the Yorktown Formation indicates that the present river systems reflect Pleistocene drainages. Three prominent geomorphic features are present: the Churchland flat; the Deep Creek swale; and the Fentress rise.

Each geologic unit shown on the map is evaluated in terms of potential use, permeability, slope stability, aquifer recharge, erosion resistance, and plasticity/sensitivity. Flood-prone areas are designated as those below 10 feet (3 m) elevation and which may be initially affected during extreme high water before run off or subsidence takes place. General load bearing capacities are depicted on the map. Extensive areas of fill indicated along the Elizabeth River show the shore line change between 1887 and 1973. The uses of four abandoned quarries are good examples of sequential land use. Sources of sand and silt are discussed.

Publication 10. GEOLOGY OF THE GROTTOES QUADRANGLE, VIRGINIA, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price $3.12 ($3.00 plus $0.12 State sales tax).

This quadrangle is located in southern Rockingham and the adjoining portion of Augusta counties in west-central Virginia. The dominant geologic structure is the deep trough of the Massanutten synclinorium, the axis of which nearly bisects the quadrangle from southwest to northeast. The synclinorium is bounded on the west by the Pulaski-Staunton fault and on the east by the west limb of the Blue Ridge anticlinorium. Bedrock consists of Cambrian and Ordovician carbonate and clastic rocks that are intruded in places by diabase dikes of Triassic age. Most of the southeastern third of the quadrangle is covered by relatively thick alluvial and colluvial deposits. The rocks, which are well-jointed and exhibit a well-developed slaty cleavage, have been metamorphosed to lower greenschist facies; metamorphism seems to be more prominant in the asymmetric-to overturned folds on the east limb of the synclinorium.

Limestone, dolomite and quartzite have been quarried for building stone and road metal, and limestone for the production of lime. Aggregate for concrete, masonry sand, and sized gravel are produced from alluvial deposits along South River.

Geologic units shown on the map are discussed with respect to slope stability, erodability, and response to ground-water withdrawals, and excavations. Reference localities described in the text are identified on the map as areas where representative exposures of 13 bedrock units may be examined. Areas of known or potential sinkhole and cave development have been identified on the map.

Publication 11. Geology of the Mount Sydney Quadrangle, Virginia, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

The Mt. Sidney quadrangle is located in west-central Virginia in Augusta and Rockingham counties with the towns of Mt. Crawford, Mt. Sidney, and Weyers Cave depicted. The salient geologic structures are the Massanutten synclinorium, the Pulaski-Staunton fault, and the Burketown structure that is bounded by the Middlebrook anticline and the Long Glade syncline. Bedrock consists of upper Cambrian and Ordovician carbonate and clastic rocks that were intruded in the west-central portion by alkalic dikes of Jurassic age. The Burketown structure is the most complex area in the quadrangle where Beekmentown and Conococheague carbonates were thrust over deformed clastic rocks of the Edinburg and Martinsburg formations. The rocks, some of which exhibit well-developed slaty cleavage, have been metamorphosed to the lowermost greenschist facies.

Crushed stone has been produced from rocks of the Beekmantown Group and could be quarried from several of the other carbonate units. High-calcium limestone of the New Market Formation has potential for development; other carbonate formations are possible sources for agricultural or hydraulic lime. Slate beds in the upper member of the Martinsburg Formation may be potential sources for brick and lightweight aggregate.

Geologic units shown on the map are discussed with respect to slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

Publication 12. Geology of the Fort Defiance Quadrangle, Virginia, by T. M. Gathright II, W. S. Henika and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State sales tax).

The Fort Defiance quadrangle is located in west-central Virginia in the northeastern part of Augusta county. Almost one-half the quadrangle is underlain by the clastic Martinsburg Formation that occurs in the trough of the Massanutten synclinorium. Carbonate rocks of Ordovician and upper Cambrian age on the west limb have only minor small-scale folds. Some are intruded by alkalic dikes of Jurassic age. The same carbonate formations on the east limb are asymmetrically folded, overturned in places, faulted in others, and have been intruded by Triassic diabase dikes. Cleavage and schistosity is well developed, and metamorphic mineral growth parallels the cleavage.

Limestone has been quarried for crushed stone and lime, and several carbonate units free from sandstone and chert have some potential for crushed stone. The New Market Limestone is a source for high-calcium limestone but its extent, thickness and steep inclination limits the quantity available for quarrying. In the upper (sandstone-bearing) member of the Martinsburg Formation slate and argillite strata have a potential for brick or lightweight aggregate where they are non-calcareous and free from sandstone..

Geologic units shown on the map are considered for slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

Publication 13. Geology of the Crimora Quadrangle, Virginia, by T. M. Gathright II, W. S. Henika, and J. L. Sullivan III; geol. map (1:24,000) with map text, one sheet, 1978. Price \$3.12 (\$3.00 plus \$0.12 State Sales tax).

The Crimora quadrangle is located in west-central Virginia in the northeastern part of Augusta and the adjoining portions of Albemarle and Rockingham counties. Steeply dipping to overturned upper Cambrian and Ordovician carbonates underlie most of the western third of the area; slate and argillite beds are present in Martinsburg Formation. Relatively thick alluvial and colluvial deposits cover the middle Cambrian carbonate formations in the central third of the area. The eastern third is underlain by clastic rocks of the lower Cambrian Chilhowe[illegible]up, and the basalts and metasediments of the [illegible]cambrian Catoctin Formation. In Blue [illegible]symmetric to overturned, closed to isoclinal, no[illegible]cylindrical folding of these rocks form the dominant physiographic and structural features.

Sand and gravel are processed from the alluvial deposits along South River, and impure carbonate from the Beekmantown Group and Conococheague Formation may be a source for crushed stone, agricultural limestone and hydraulic lime. Manganese deposits occur along the west foot of the Blue Ridge; at one time the Crimora mine was the largest producer of manganese in the United States.

Geologic units shown on the map have been evaluated for slope stability, erodability, and response to ground-water withdrawals, and excavation. Areas of known or potential sinkhole and cave development have been identified on the map, as are reference localities for representative exposures of several formations.

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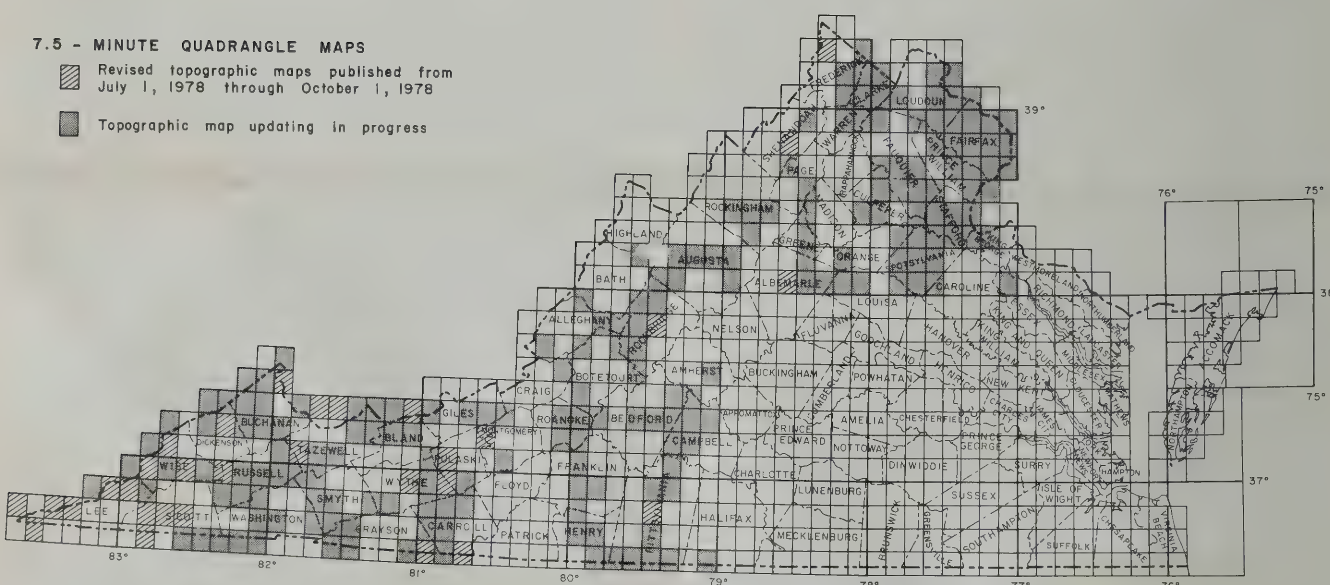
TOPOGRAPHIC MAPS



Revised 7.5-minute quadrangle maps published from July 1 through October 1, 1978:

Appalachia	Cumberland Knob	Fosters Falls	Keokee	Princeton	St. Paul
Cana	Duffield	Gary	Lexington	Pulaski	War
Charlottesville West	Edinburg	Gate City	Panther	Radford North	Wheeler
Chatham	Ewing	Gore	Pennington Gap	Richlands	Wise
Clinchport	Flat Gap	Haysi	Plum Grove	Rose Hill	Wytheville

ADVANCE PRINTS

Advance prints are available at $1.25 each from the Eastern Mapping Center, Topographic Division, U.S. Geological Survey, Reston, Virginia 22902.

PUBLISHED TOPOGRAPHIC MAPS

Total State coverage completed; index is available free. Updated photorevised maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published maps for all of Virginia are available at $1.25 each (plus 4 percent State sales tax for Virginia residents) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903.

VIRGINIA MINERALS

COMMONWEALTH OF VIRGINIA
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SUMMARY OF COAL RESOURCES IN VIRGINIA

James A. Henderson, Jr.

Coal occurs in three areas in Virginia (Figure 1): the Richmond and Farmville basins, the Valley coal fields, and the Southwest Virginia coal field. In 1975 Virginia ranked 6th in total shipments of bituminous coal (Westerstrom and Harris, 1977). Production in 1977 was 37,513,131 million short tons (34,025,515 metric tons) from the Southwest Virginia coal field. Approximately 33 percent of the total production in 1977 was by strip-mining methods (Virginia Department of Labor and Industry, 1978).

Figure 1. Index map of Virginia coal fields.

Coal has been mined in Virginia since colonial times from Triassic-age rocks in the Richmond and Farmville basins. Initial production was from the Richmond basin that lies within parts of Amelia, Chesterfield, Goochland, Henrico, and Powhatan counties. The coal in this field is chiefly bituminous and in some areas has been altered to coke by igneous intrusions. Mining began in the Richmond basin in the early 1700's and continued into the early part of this century. Cumulative production for the Richmond basin was slightly more than 8 million short tons (7 million metric tons) (Brown & Others, 1952). The Farmville basin contains some coal that was mined in Cumberland County in the late 1800's.

The Valley coal fields lie within 10 small areas in Augusta, Bland, Botetourt, Montgomery, Pulaski, Roanoke, Rockingham, Smyth, and Wythe counties. The coal in these fields is Mississippian in age and is of semianthracite and bituminous rank. Mining began in the Valley fields before the 1860's and continued until 1971. Cumulative production from the Valley coal fields is about 7 million short tons (6 million metric tons) (Brown and Others, 1952).

All current production is from the Southwest Virginia coal field in Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise counties. The coal is of Pennsylvanian age and ranges from high- to low-volatile bituminous in rank. Mining in this field began in the 1880's.

The coal-bearing strata in the Southwest Virginia coal field are generally flat lying to gently dipping. The upturned leading edge of the Cumberland thrust sheet forms the northwestern limit of the coal field in Dickenson and Wise counties. To the northeast and southwest, the Southwest Virginia field extends to the West Virginia and Kentucky state lines respectively. The southeastern edge of the coal field is bounded in Russell and Tazewell counties by a series of thrust faults. In Wise County the Pigeon Creek flexure and the Powell Valley anticline form the southeastern edge of the coal field. Other major structural features of the field are the Russell Fork fault, a northwest

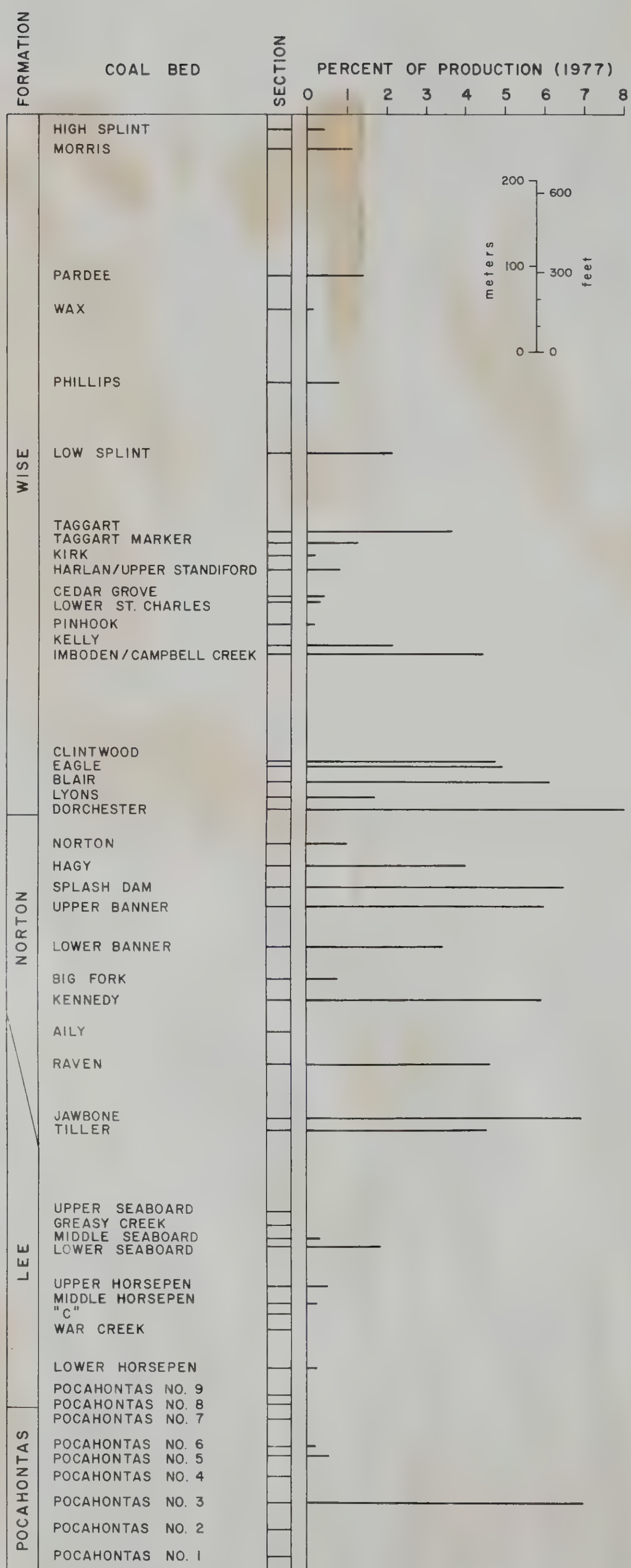

Figure 2. Generalized stratigraphic section of the Southwest Virginia coal field and percent of production data by bed for 1977.

trending strike-slip fault in Buchanan and Dickenson counties and the Middlesboro syncline that extends northeastward from Kentucky into Wise County.

The coal occurs in a sequence of sandstone, siltstone, shale, and occasional thin clastic and calcareous zones of marine origin. The oldest formation is the Pocahontas Formation, which is exposed at the surface in Tazewell County. This formation is present in the subsurface in Buchanan, Dickenson, Russell, Scott, and Wise counties. The Pocahontas coals (Figure 2, Nos. 1-7) are the important coals in this formation and are low-volatile bituminous in rank. The Pocahontas Formation is overlain in the central and southwestern part of the coal field by the Lee Formation. The Lee Formation may be partially equivalent to the New River Formation of West Virginia. Coals of the Lee Formation are shown in Figure 2. It contains three prominent quartz arenite beds 100 to 450 feet (30 to 137 m) thick and separated by 200 to 500 feet (61 to 152 m) of siltstone, sandstone, shale, and coal (Miller, 1974). Immediately above the Lee Formation is the Norton Formation, which includes the Kennedy, Big Fork, Lower Banner, Upper Banner, Splash Dam, Hagy, and Norton coals. The Norton Formation in places includes the Tiller, Jawbone, Raven, and Aily coals because of a thinning of the Lee Formation in a southeasterly direction (Miller, 1974). The youngest coal-bearing formation in the Southwest Virginia field is the Wise Formation. Coal beds in this formation are shown in Figure 2.

Total coal production and strip mine production for the years 1915 to present are shown in Figure 3. Pre-1950 data are from Brown and Others (1952), and data for 1950 to the present are from the Annual Reports of the Virginia Department of Labor and Industry. Strip mining began prior to 1950, but because of incomplete data, the production curve is not shown before that year.

In 1977, total coal production in Virginia was approximately 37.5 million short tons (34 million metric tons) as reported by the Virginia Department of Labor and Industry. Figure 2 shows the production by individual bed; beds with reported production less than 0.1 percent of the total or approximately 37,000 short tons (33,560 metric tons) were excluded. Vertical intervals shown between coal beds are approximate. Production figures for the Imboden and Campbell Creek coals were reported separately but are shown together in this figure because they are known to be the same coal (Brown and Others, 1952). The same rationale was used for the Harlan/Upper Standiford entry. A coal may have more than one name in different parts of the Southwest Virginia coal field.

POCAHONTAS FORMATION

Pocahontas No. 1 and 2 Coal Beds: The Pocahontas No. 1 and 2 coal beds are generally thin and are not economic at present (Miller, 1974).

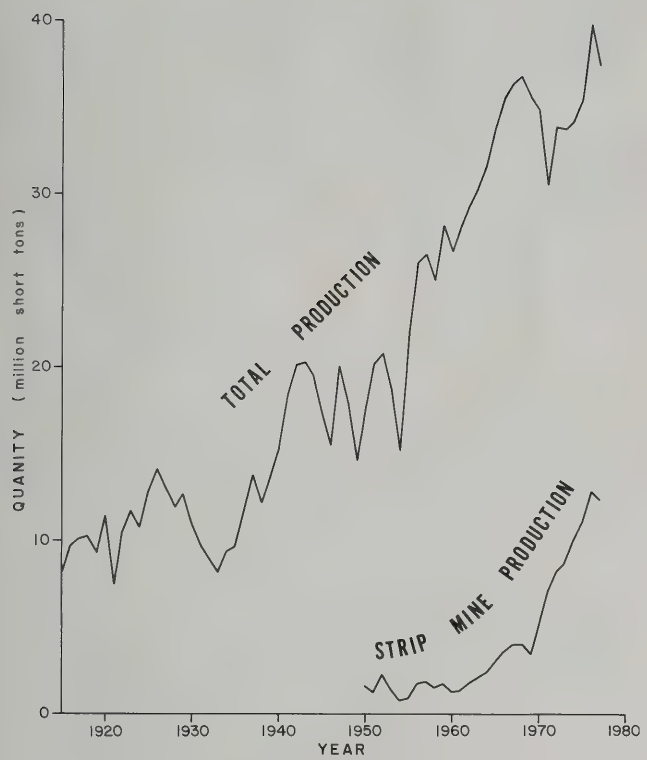

Figure 3. Total coal production since 1915 and strip mine production since 1950 for Virginia.

Pocahontas No. 3 Coal Bed: The Pocahontas No. 3 coal bed is the most economically important of the Pocahontas Formation coals. This bed crops out in Tazewell County and is present in the subsurface in Buchanan, Dickenson, Russell and Wise counties. The Pocahontas No. 3 and other coals of the Pocahontas Formation may be equivalent to the coal at Burtons Ford in Russell County and southwest into Scott County. The Pocahontas No. 3 is a medium- to low-volatile bituminous coal and ranges in thickness from 1.7 to 11 feet (0.51 to 3.35 m) with a usual thickness of between 4 to 5 feet (1.2 to 1.5 m). Most of the present Pocahontas No. 3 production is from shaft mines in Buchanan County where the coal is about 1300 feet (396 m) below the surface (Brown and Others, 1952 and Miller, 1974). The range of analyses for the Pocahontas No. 3 coal on an as-received basis is as follows (U. S. Bureau of Mines, 1944 and Swanson and Others, 1976):

Moisture (%)	0.8- 2.3
Volatile matter (%)	15.3-22.8
Fixed carbon (%)	68.9-76.0
Ash (%)	3.3-16.0
Sulfur (%)	0.5- 0.9
BTU	12,840-14,940

Pocahontas No. 4 Coal Bed: The Pocahontas No. 4 coal bed is approximately 30 to 120 feet (9 to 37 m) above the Pocahontas No. 3 coal bed. The coal crops out in Tazewell County and is present in the subsurface in Buchanan, Dickenson, Russell, and Wise counties. The Pocahontas No. 4 coal is a low-volatile bituminous coal and ranges from 1.2 to 7 feet (0.36 to 2.13 m) in thickness (Brown and Others, 1952 and Miller, 1974).

Pocahontas No. 5 Coal Bed: The Pocahontas No. 5 coal is 35 to 100 feet (11 to 30 m) above the Pocahontas No. 4 coal bed. The coal crops out in Tazewell County and is present in the subsurface in Buchanan, Dickenson, Russell, and Wise counties. The Pocahontas No. 5 coal ranges in thickness from 1.2 to 7 feet (0.36 to 2.13 m) and is a medium-volatile bituminous coal (Brown and Others, 1952 and Miller, 1974).

Pocahontas No. 6 Coal Bed: The Pocahontas No. 6 coal is approximately 200 feet (61 m) above the Pocahontas No. 3. The No. 6 crops out in Tazewell County and is present in the subsurface in Buchanan and Russell counties. This coal is generally less than two feet (0.61 m) thick (Miller, 1974).

Pocahontas No. 7 Coal Bed: The Pocahontas No. 7 coal bed crops out in Tazewell County and is present in the subsurface in Buchanan and Russell counties. This coal is generally less than two feet (0.61 m) thick (Miller, 1974).

LEE FORMATION

Pocahontas No. 8 and 9 Coal Beds: The Pocahontas No. 8 and 9 coal beds are the lowest coal beds in the Lee Formation. They crop out in Tazewell County and are present in the subsurface in Buchanan County. These coals are normally less than one foot (0.3 m) thick (Miller, 1974).

Lower Horsepen Coal Bed: The Lower Horsepen coal is 100 to 150 feet (30 to 46 m) above the base of the Lee Formation. The coal crops out in Tazewell County and is present in the subsurface in Buchanan County. This coal may also be present in the subsurface in other parts of the coal field. The Lower Horsepen coal ranges in thickness from 1.5 to 2.5 feet (0.46 to 0.76 m) (Miller, 1974).

War Creek Coal Bed: The War Creek coal bed is 120 to 170 feet (37 to 52 m) above the Lower Horsepen coal and is present in Buchanan, Dickenson, Russell, Scott, Tazewell, and Wise counties. The coal is up to six feet (1.8 m) thick in Buchanan County (Miller, 1974).

Middle Horsepen Coal Bed: The Middle Horsepen coal bed is about 100 feet (30.5 m) above the War Creek coal. The coal crops out in Tazewell County and is present in the subsurface in Buchanan and possibly other counties in the coal field. The Middle Horsepen coal is generally less than two feet (0.61 m) thick (Miller, 1974). An average of two analyses of Middle Horsepen coal on an as-received basis is as follows (Thomson and York, 1975):

Moisture (%)	3.2
Ash (%)	9.2
Sulfur (%)	0.5
BTU	13,730

Upper Horsepen Coal Bed: The Upper Horsepen coal bed is about 50 feet (15 m) above the Middle Horsepen coal. The coal crops out in Tazewell County and is present in the subsurface in Buchanan County and possibly in other counties in the coal field. The Upper Horsepen coal is generally less than two feet (0.61 m) thick (Miller, 1974).

Seaboard Coal Beds: The Seaboard coal beds are made up of the Lower Seaboard coal (about 150 feet, 46 m, above the Upper Horsepen), the Middle Seaboard coal (about 30 feet, 9 m, above the Lower Seaboard), and the Upper Seaboard coal (about 90 to 110 feet, 27 to 34 m) above the Middle Seaboard. These coal beds are generally less than two feet (0.61 m) (Miller, 1974) thick. Most of the Lower and Middle Seaboard production is from Tazewell County.

Tiller Coal Bed: The Tiller coal bed is about 300 to 325 feet (91 to 99 m) above the Upper Seaboard coal and crops out in Buchanan, Dickenson, Russell, Tazewell and Wise counties. In the first four counties the Tiller coal and the overlying coals in the Lee Formation are included in the Norton Formation where the Bee Rock Sandstone Member (upper quartz arenite) of the Lee Formation is absent. The Tiller coal ranges in thickness from 1.5 to 5 feet (0.46 to 1.5 m) (Miller, 1974). Most of the production for the Tiller coal bed is from Buchanan, Dickenson, and Russell counties. The range of analyses for the Tiller coal bed on an as-received basis is as follows (U.S. Bureau of Mines, 1944 and Swanson and Others, 1976):

Moisture (%)	1.8- 3.0
Volatile Matter (%)	26.7-32.5
Fixed carbon (%)	56.8-63.8
Ash (%)	6.1-12.2
Sulfur (%)	0.4- 0.7
BTU	13,260-14,180

Jawbone Coal Bed: The Jawbone coal bed is a high-volatile A to low-volatile bituminous coal and may be as much as 100 feet (30 m) above the Tiller coal bed, although in some places the two coals join to form one bed. The Jawbone coal is present in Buchanan, Dickenson, Russell, Tazewell and Wise counties. This coal is as much as 6.5 feet (2 m) thick, and when combined with the Tiller coal may form a coal zone of more than 15 feet (4.6 m) (Miller, 1974). Most of the production for the Jawbone coal is from Buchanan, Russell, and Wise counties. The range of analyses for the Jawbone coal on an as-received basis is as follows: (U. S. Bureau of Mines, 1944 and Swanson and Others. 1976):

Moisture (%)	1.2- 4.3
Volatile Matter (%)	17.9-32.9
Fixed carbon (%)	45.2-71.2
Ash (%)	6.5-30.9
Sulfur (%)	0.5- 1.2
BTU	10,070-14,250

Raven Coal Bed: The Raven coal bed is a high-volatile A to medium-volatile bituminous coal and is as much as 200 feet (61 m) above the Jawbone coal. The coal crops out in Buchanan, Dickenson, Russell, and Wise counties. The thickness ranges from less than 2 feet to 6 feet (0.61 to 1.8 m) (Miller, 1974). Most of the Raven coal production is from Buchanan County. The range of analyses for the Raven coal on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.4- 5.5
Volatile matter (%)	28.9-33.4
Fixed carbon (%)	55.1-63.9
Ash (%)	2.8-12.2
Sulfur (%)	0.4- 0.8
BTU	12,980-14,940

Aily Coal Bed: The Aily coal bed is 100 to 150 feet (30 to 46 m) above the Raven coal. The coal crops out in Buchanan, Dickenson, Russell, Tazewell, and Wise counties and ranges in thickness from 1.5 to 3 feet (0.46 to .9 m) (Miller, 1974).

NORTON FORMATION

Kennedy Coal Bed: The Kennedy coal bed is 30 to 150 feet (9 to 46 m) above the Aily coal and crops out in Buchanan, Dickenson, Russell, Tazewell and Wise counties. The coal ranges from 2 to 10 feet (0.61 to 3 m) thick (Miller, 1974). Most of the 1977 Kennedy coal production is from Buchanan County. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944 and Swanson and Others, 1976):

Moisture (%)	1.6- 4.7
Volatile matter (%)	25.0-36.4
Fixed carbon (%)	43.2-69.0
Ash (%)	3.3-27.0
Sulfur (%)	0.5- 2.0
BTU	10,380-14,790

Big Fork Coal Bed: The Big Fork coal bed is 30 to 150 feet (9 to 46 m) above the Kennedy coal in Buchanan, Russell, and Tazewell counties. The coal is from two to three feet (0.61 to 0.91 m) thick (Brown and Others, 1952). All production from the Big Fork coal was from Russell County in 1977.

Lower Banner Coal Bed: The Lower Banner coal bed is 180 to 275 feet (55 to 84 m) above the Kennedy coal and crops out in Buchanan, Dickenson, Russell, and Wise counties. The thickness of the coal ranges from two to six feet (0.61 to 1.83 m) (Brown and Others, 1952). Most of the Lower Banner coal production was from Buchanan and Dickenson counties in 1977. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944 and Swanson and Others, 1976):

Moisture (%)	1.2- 8.1
Volatile matter (%)	20.1-36.6
Fixed carbon (%)	54.6-70.9
Ash (%)	5.2-11.2
Sulfur (%)	0.4- 1.9
BTU	13,030-14,630

Upper Banner Coal Bed: The Upper Banner coal bed is approximately 30 to 150 feet (9 to 46 m) above the

Lower Banner coal. The coal crops out in Dickenson, Russell, and Wise counties and is a high-volatile A bituminous coal. The Upper Banner ranges in thickness from 4 to 7 feet (1.22 to 2.13 m) (Brown and Others, 1952). Most of the 1977 production from the Upper Banner coal was from Dickenson and Wise counties. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944 and Swanson and Others, 1976):

Moisture (%)	1.6- 3.9
Volatile matter (%)	30.4-37.4
Fixed carbon (%)	51.9-63.1
Ash (%)	4.1-14.4
Sulfur (%)	0.5- 1.3
BTU	12,660-14,690

Splash Dam Coal Bed: The Splash Dam coal bed is 60 to 90 feet (18 to 27 m) above the Upper Banner coal and crops out in Buchanan, Dickenson, Russell and Wise counties. The coal ranges in thickness from 1 to 4 feet (0.3 to 1.2 m) (Brown and Others, 1952). Most of the Splash Dam coal production in 1977 was from Buchanan and Dickenson counties. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.0- 4.3
Volatile matter (%)	25.0-31.3
Fixed carbon (%)	56.2-64.8
Ash (%)	4.4-17.6
Sulfur (%)	0.6- 1.6
BTU	12,690-14,430

Hagy Coal Bed: The Hagy coal bed ranges from 80 to 110 feet (24 to 34 m) above the Splash Dam coal and crops out in Buchanan, Dickenson, and Wise counties. The Hagy coal is from 1.2 to 4 feet (0.37 to 1.2 m) in thickness (Brown and Others, 1952). Most of the production from the Hagy coal was from Buchanan County in 1977. The average analysis for four samples on an as-received basis is as follows (Thomson and York, 1975):

Moisture (%)	2.3
Ash (%)	8.1
Sulfur (%)	1.8
BTU	13,880

Norton Coal Bed: The Norton coal bed is 90 to 370 feet (27 to 113 m) above the Hagy coal and crops out in Dickenson and Wise counties. The coal is as much as 5 feet (1.5 m) thick near Norton (Brown and Others, 1952). The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	2.1- 4.1
Volatile matter (%)	31.2-33.5
Fixed carbon (%)	56.1-58.2
Ash (%)	6.4-10.2
Sulfur (%)	0.8- 1.5
BTU	13,390-13,900

WISE FORMATION

Dorchester Coal Bed: The Dorchester coal bed is the lowest coal bed in the Wise Formation. The coal ranges in thickness from 1.5 to 6 feet (0.46 to 1.83 m) and crops out in Buchanan, Dickenson, Lee, Russell, and Wise counties (Brown and Others, 1952). Most of the 1977 production from the Dorchester coal was from Buchanan and Wise counties. The range of analyses for the Dorchester coal on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.2- 5.3
Volatile matter (%)	25.8-36.1
Fixed carbon (%)	53.4-63.4
Ash (%)	2.2-16.1
Sulfur (%)	0.6- 2.9
BTU	12,710-14,570

Lyons Coal Bed: The Lyons coal bed is 40 to 75 feet (12 to 23 m) above the Dorchester coal and crops out in Dickenson, Lee, and Wise counties. The coal ranges from 1.3 to 2.7 feet (0.4 to 0.82 m) in thickness (Brown and Others, 1952). Most of the Lyons coal production in 1977 was from Wise County.

Blair Coal Bed: The Blair coal bed is about 60 feet (18 m) above the Dorchester coal in Buchanan county and from 20 to 80 feet (6 to 24 m) above the Lyons coal in Dickenson, Lee, and Wise counties. The coal ranges from 1.5 to 4 feet (0.45 to 1.2 m) thick (Brown and Others, 1952). Most of the Blair coal production in 1977 was from Buchanan and Wise counties. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.5-11.0
Volatile matter (%)	25.9-35.2
Fixed carbon (%)	50.6-64.2
Ash (%)	2.0-20.2
Sulfur (%)	0.5- 3.9
BTU	11,910-14,490

Eagle Coal Bed: The Eagle coal bed is 45 to 50 feet (14 to 15 m) above the Blair coal and crops out in Buchanan, Dickenson, and Wise counties. The coal is from 1.3 to 5 feet (0.4 to 1.5 m) thick (Brown and Others, 1952). Most of the Eagle coal production was from Buchanan and Dickenson counties in 1977.

Clintwood Coal Bed: The Clintwood coal bed is 70 to 150 feet (21 to 46 m) above the Blair coal and crops out in Buchanan, Dickenson, Lee, and Wise counties. The coal ranges in thickness from 2.5 to 11 feet (0.76 to 3.35 m) (Brown and Others, 1952). Most of the Clintwood coal production in 1977 was from Buchanan, Dickenson and Wise counties. The range of analyses for the coal on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.3-3.2
Volatile matter (%)	30.5-38.5
Fixed carbon (%)	56.1-61.9
Ash (%)	2.2- 8.5
Sulfur (%)	0.7- 1.7
BTU	12,780-14,530

Imboden Coal Bed: The Imboden coal bed is 225 to

500 feet (69 to 152 m) above the Clintwood coal and crops out in Buchanan, Dickenson, Lee and Wise counties. The thickness of the Imboden coal ranges from 1.5 to 10 feet (0.46 to 3 m). In Buchanan County and parts of Dickenson County, the Imboden coal is called the Campbell Creek coal (Brown and Others, 1952). Most of the 1977 production from the Imboden coal was from Wise County. The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1955):

Moisture (%)	1.8- 2.8
Volatile matter (%)	33.0-35.7
Fixed carbon (%)	53.6-61.3
Ash (%)	4.0-10.4
Sulfur (%)	0.6- 0.9
BTU	13,310-14,450

Kelly Coal Bed: The Kelly coal bed is 20 to 70 feet (6.1 to 21 m) above the Imboden coal in Dickenson, Lee, and Wise counties. The coal is as much as 4.8 feet (1.46 m) thick in Wise County (Brown and Others, 1952). In 1977, most of the production from the Kelly coal was from Wise County.

Harlan Coal Bed: The Harlan coal bed is approximately 250 feet (76 m) above the Kelly coal and crops out in Lee and Wise counties. In parts of its outcrop area, the Harlan coal is called the Upper Standiford coal. The coal ranges from 2.7 to 6.5 feet (0.82 to 1.98 m) thick (Brown and Others, 1952). Most of the 1977 production from the Harlan coal was from Wise County.

Taggart Marker Coal Bed: The Taggart Marker coal bed is approximately 380 feet (116 m) above the Kelly coal and crops out in Lee and Wise counties. The coal ranges in thickness from 1.5 to 3.5 feet (0.46 to 1.1 m) (Brown and Others, 1952). All of the Taggart Marker coal production in 1977 was from Wise County. The range of analyses on an as-received basis for the Taggart Marker coal is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.5- 6.4
Volatile matter (%)	33.5-37.5
Fixed carbon (%)	55.9-59.4
Ash (%)	2.5- 5.6
Sulfur (%)	0.5- 0.8
BTU	13,810-14,800

Taggart Coal Bed: The Taggart coal bed is 20 to 75 feet (6.1 to 23 m) above the Taggart Marker coal and crops out in Lee and Wise counties. The coal ranges in thickness from 2.8 to 6.5 feet (0.85 to 1.98 m) (Brown and Others, 1952). The range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	1.5- 4.3
Volatile matter (%)	32.8-38.4
Fixed carbon (%)	55.4-61.6
Ash (%)	1.7- 4.6
Sulfur (%)	0.4- 0.8
BTU	13,720-14,810

Low Splint Coal Bed: The Low Splint coal bed is 200 to 400 feet (61 to 122 m) above the Taggart coal and crops out in Lee and Wise counties. The coal ranges from 2.5 to 5.5 feet (0.76 to 1.68 m) thick (Brown and Others, 1952). A range of analyses on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	2.1- 3.7
Volatile matter (%)	34.5-37.5
Fixed carbon (%)	51.3-54.7
Ash (%)	5.6-10.5
Sulfur (%)	0.7- 1.1
BTU	12,790-13,910

Phillips Coal Bed: The Phillips coal bed is 250 to 400 feet (76 to 122 m) above the Low Splint coal and crops out in Lee and Wise counties. The coal ranges from 2 to 4 feet (0.61 to 1.22 m) in thickness (Brown and Others, 1952).

Pardee Coal Bed: The Pardee coal bed is 275 to 400 feet (84 to 122 m) above the Phillips coal and crops out in Lee and Wise counties. The coal ranges from 4.5 to 11 feet (1.37 to 3.35 m) in thickness (Brown and Others, 1952). All of the 1977 production from the Pardee coal was from Wise County. The range of analyses on an as-received basis for the Pardee coal is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	2.0- 5.1
Volatile matter (%)	32.4-37.8
Fixed carbon (%)	48.8-57.5
Ash (%)	3.9-12.0
Sulfur (%)	0.7- 1.4
BTU	12,430-14,240

Morris Coal Bed: The Morris coal bed is 350 to 650 feet (107 to 198 m) above the Pardee coal and crops out in Lee and Wise counties. The Morris coal ranges from 3.0 to 3.5 feet (0.91 to 1.07 m) in thickness (Brown and Others, 1952). In 1977 all of the Morris coal production was from Wise county.

High Splint Coal Bed: The High Splint coal bed is about 70 feet (21 m) above the Morris coal and crops out in Lee and Wise counties. The High Splint coal ranges in thickness from 4 to 5 feet (1.22 to 1.52 m) (Brown and Others, 1952). Most of the 1977 High Splint coal production was from Wise County. A range of analyses for the High Splint coal on an as-received basis is as follows (U. S. Bureau of Mines, 1944):

Moisture (%)	2.7- 3.6
Volatile matter (%)	30.8-35.3
Fixed carbon (%)	48.6-60.2
Ash (%)	3.6-17.0
Sulfur (%)	0.5- 0.8
BTU	11,850-14,120

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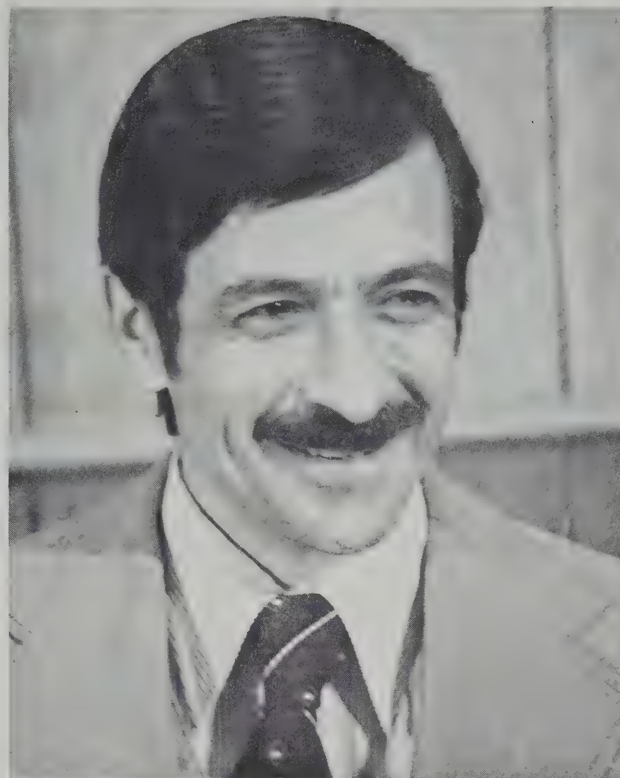
ACADEMY GEOLOGY SECTION MEETING

Information on geologic research will be given at the 1979 annual meeting Geology Section of the Virginia Academy of Science at the University of Richmond on May 10-11, 1979. In addition to formal talks poster sessions, where an author explains his research with the aid of a display, will be featured. Details on making presentations at the meeting can be obtained before March 1, 1979 from Roddy V. Amenta, Dept. of Geology, James Madison University, Harrisonburg, Va. 22801. All interested in the geology of the State are invited to attend. A $50 cash prize will be awarded for the best student paper by the Virginia Geology Field Conference.



NEW STATE GEOLOGIST

Dr. Robert C. Milici became the State Geologist and Commissioner of the Virginia Division of Mineral Resources January 1, 1979. His selection resulted from an evaluation of applicants from many parts of the nation. The recruitment committee represented consultants, private industry, and educational institutions. Since Dr. James L. Calver's retirement in mid 1978, Dr. Bruce Hobbs has ably directed the activities of the Division.

Bob was born in New Haven, Connecticut in 1931, and spent his early life in Kings Park, New York, which at that time was a small rural community on the north shore of Long Island. He spent many happy summers there, boating and working as a bayman on Long Island Sound. Upon graduating from High School, he entered Cornell University and obtained an A. B. degree from that institution in 1954, with a major in Geology. He then moved to the Southern Appalachian mountains, to the University of Tennessee, for graduate work and obtained an M. S. degree in 1955 and a Ph. D. degree in 1960. His theses were concerned with Paleozoic stratigraphy and structure of the Valley and Ridge and Cumberland Plateau. From 1958-1961 and 1964-1978 he was employed by the Tennessee Division of Geology. While there the position of Chief Geologist of Research was attained. During 1962-1963 he was an employee of the Virginia Division of Mineral Resources.

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He met his wife to be, Patricia Hankley of Galax, Virginia, in graduate school at the University of Tennessee. They have two children, Pamela Ann 18 and Craig 16. He has continued with hobbies of boating and fishing on the lakes of East Tennessee, and, along with his children, became involved with coaching recreational baseball and basketball teams in Knoxville. In addition, he enjoys landscape gardening and photography.

His numerous publicaitons include descriptions of the structure, stratigraphy, and geomorphology of Paleozoic age rocks in the Valley and Ridge and Cumberland Plateau areas of Tennessee. He has explained his research on many field trips, especially those with Southeastern Geological Society of America meetings. While employed in Virginia he was principal compiler of the 1963 Geologic Map of Virginia. He was also a co-author of Bulletin 79, Geology and Mineral Resources of Fluvanna County.

Dr. Milici's leadership at the Division will involve accelerated geologic mapping and geophysical and geochemical studies, especially in economic interest areas. Studies of energy resources such as coal, gas, and oil in southwest Virginia will be expanded. Cooperative geologic programs will be developed with the State's colleges and universities and the U. S. Geological Survey. Industry will be assisted in the identification of mineral deposits. Regional compilations of mineral resources and commodity studies will continue. Topographic maps will be kept up-to-date. Additional base maps at scales of 1:50,000 and 1:100,000 are to be continued.

ADDITIONAL ORTHOPHOTO-QUADS AND MAP REVISION

About 15% of the State now has orthophotoquad coverage due to the addition of the 43 quadrangles along the Virginia-North Carolina boundary. These quadrangles became available upon the completion of the North Carolina-U. S. Geological Survey statewide orthophotoquad coverage program.

Orthophotoquads are black and white aerial photographic depictions of 1:24,000 scale topographic map areas. By comparing these with their corresponding maps the following can be interpreted: land-use, differentiation of deciduous from coniferous forests, and location of individual properties. At $1.25 each (plus $0.05 tax to Virginia addresses) these inexpensive aerial photographs provide a useful information tool as well as an interesting wall display. A listing of available orthophotoquads is available on request.

Some 69 topographic maps in Revision Inspection Sector 2 have been selected to be updated at a meeting of Division and U. S. Geological Survey personnel. These maps will include the cities of Emporia, Franklin, Hampton, Newport News, Norfolk, Poquoson, Williamsburg, and Virginia Beach. Since obtaining modern coverage in 1972, some of these maps will now have been revised three times. This is part of a continuing effort to keep maps in growth areas up-to-date. Changes in corporate boundaries will now be shown on photorevised maps.

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DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
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RADIOACTIVITY SURVEYS

Stanley S. Johnson

Radioactivity surveys have been used since the late 1940's in the exploration for uranium and uranium-bearing rocks. From the early 1960's the airborne technique has progressed from the simple geiger counter and similar type instruments used in "anomaly hunting" to the highly sophisticated gamma-ray spectrometers with detectors having thousands of cubic inches in sensing crystal volume. Aeroradioactivity surveys are used increasingly for regional geologic studies and uranium exploration.

The use of radioactivity in geologic studies is based on the presence in rocks of the radioactive elements uranium and thorium, and a radioactive isotope of potassium. These elements and/or their isotopes emit gamma rays that can be detected with instruments such as geiger counters, scintillometers, electrometers, and spectrometers. Measurements of the radioactive properties of naturally occurring elements indicate that a low level of radioactivity is present in almost all rocks and minerals. The radioactivity of a particular rock and its weathered product is dependent upon the concentration of radioactive elements initially present and the change that the rock has undergone. Weathering and metamorphism are important in modifying the re-distribution of radioactive elements. In measuring radioactivity accurately, there are more variables than any other geophysical technique (Table 1).

RADIOACTIVITY

There are at least twenty naturally occurring elements that are radioactive, but only potassium, uranium and thorium are of use in radioactivity surveys. Other elements are either so rare or emit gamma rays that are so weak, or both, that they cannot be used.

There are four sources of gamma radiation that influence the reading obtained by crystal detectors in airborne survey equipment: (1) Cosmic radiation originates from outer space and gives low level, high-energy radiation. (2) Radioactive nuclides are produced by nuclear detonations ("fall-out"). Generally these isotopes will not interfere with the higher energy levels that the detectors are set to measure (Table 2). Except near the source of origin "fall-out" has not affected the contrast in radioactivity between adjoining lithologic units. (3) Radioactive nuclides occur naturally in the atmosphere, namely radon-222 and bismuth-214. (4) Natural radioactive nuclides are present in the surficial layers of soil and rock.

The use of radioactivity in geology and mineral exploration is based on several properties of gamma radiation: the penetrating power of gamma rays, the characteristic energy level of the individual elements, and the energy peak used for the detection of the individual element. To avoid interferences this peak must be isolated from adjacent peaks emitted by other

Table 1. Factors that should be considered in an aeroradioactivity survey.

Instrumentation
- size, efficiency, and speed of detector
- drift and temperature stabilization
- sensitivity
- calibration
- instrument and aircraft background
- elevation of survey above terrain

Atmosphere Conditions
- inversions (air)
- pressure (air)
- movement (air)
- precipitation
- fallout
- cosmic rays
- radon depletion (at surface)
- stability (air)
- moisture

Geology and Mineralogy
- topography and structural trends
- flight line direction and spacing
- cultural effects
- abundance of isotopes in ground
- solubility of uranium and thorium
- emanating power of soil and rock
- dis-equilibrium conditions in decay series
- thickness of radiation source
- burial of radiation source

Data Reduction and Compilation
- flight path recovery
- Compton stripping ratio
- background count
- live time
- Compton scatter
- altitude correction

Table 2. Thermonuclear fission products (Hansen, 1975).

Element	Isotope	Gamma-ray Radiation energy (MeV)	Half-life
Strontium	Sr- 89	———	50.5 day
Strontium	Sr- 90	———	27.7 yr
Yttrium	Y- 90	1.75	64.2 hr
Yttrium	Y- 91	1.19	57.5 day
Zirconium	Zr- 95	0.73	65 day
Niobium	Nb- 95	0.76	35 day
Ruthenium	Ru-103	0.56	40 day
Ruthenium	Ru-106	———	1 yr
Rhodium	Rh-106	1.56, 1.23, 1.07, 0.80, 0.74	1.3 min
Iodide	I-131	0.37	8.08 day
Cesium	Cs-137	0.66	26.6 yr
Barium	Ba-140	0.5	12.8 day
Lanthanum	La-140	1.6, 2.3	40 hr
Cerium	Ce-144	0.13, 0.08	285 day

Note: There are more than 100 radionuclides produced in a thermonuclear explosion by fission and neutron reactions. Some of the more prominent fission products are listed in this table.

elements in the energy spectrum. The gamma radiation measured for survey purposes comes from the daughter isotopes of uranium-238, thorium-232, and potassium (Table 3). The significant isotopes are bismuth-214 (from uranium-238), thallium-208 (from thorium-232) and potassium-40 (from potassium). They are used because of the distinctive energy peak that is emitted by each element.

In the case of uranium-238, only a few gamma rays are capable of detection. They are of such low energy and yield that they cannot be easily detected. Bismuth-214 is used for the detection of uranium because it has a sufficient yield (19 percent) of high energy gamma radiation at 1.76 MeV. Thallium-208 is used for detection of thorium-232 because it has a peak of high energy gamma radiation at 2.62 MeV that gives a yield of 100 percent. Potassium-40 has only one energy level at 1.46 MeV. The detection of isotopes at ground level and in the air is totally dependent upon the distinct energy peak emitted by each individual element (Table 3).

Gamma radiation recorded with a spectrometer is indicative of uranium and thorium only if these elements are in equilibrium with their daughter isotopes that emit the gamma rays (Hansen, 1975). Geologic conclusions (i.e. yield estimates of uranium and thorium content of the rock) based upon parent isotopic abundances derived from gamma spectral data must involve an assumption of equilibrium (Hansen, 1975). Within a few feet of the earth's surface, equilibrium between parent and daughter isotopes is uncommon because of weathering conditions and long half lives of these very mobile isotopes in the uranium-238 series. Equilibrium is common in the thorium-232 series because the daughter isotopes are not very mobile and their half-lives are short.

The concentration of isotopes available in the uranium and the thorium decay series is directly proportional to the half-life of those isotopes. A state of disequilibrium is present when all or part of one or more daughter isotopes or parent elements is physically removed from the decay series. Disequilibrium is quite common when radon-222, uranium-234, and radium-226, are removed from the series because of the solubility and mobility of these isotopes. The bismuth-214 measured by aerial surveys is a daughter of radium-226. Radon-222 is longer-lived and contributes to the greater potential for disequilibrium in the uranium-

238 series as compared with the shorter-lived radon-220 of the thorium-232 series (Table 3).

The intensity of radiation is proportional to the abundance of the isotopes present in the ground. The thickness of the contributing source also influences the intensity measured. The highest radiometric values generally occur over an exposed outcrop. In general, detection is limited to the upper foot of an outcrop area or overlying soil. However in loose soils the depth of detection may be somewhat greater, but generally less than two feet. Moisture plays an effective part in the masking or absorption of gamma rays. For all practical purposes, gamma radiation is effectively masked by 8 to 12 inches of rock, 1 to 2 feet of soil, or 1 to 3 feet of water. However, deeper sources of radiation may be detected due to the migration of radon-222.

Table 3. Natural radioactive decay series of uranium-238, thorium-232, and potassium.

Element[1]	Isotope (mass no. and symbol)	Approximate Half-Life
Uranium-238 Series		
X Uranium	$_{92}U^{238}$	4.51×10^9 yr
Thorium	$_{90}Th^{234}$	24.1 day
Protoactinium	$_{91}Pa^{234}$	6.8 hr
X Uranium	$_{92}U^{234}$	2.47×10^5 yr
X Thorium	$_{90}Th^{230}$	8×10^4 yr
X Radium	$_{88}Ra^{226}$	1600 yr
X Radon	$_{86}Rn^{222}$	3.8 day
Polonium	$_{84}Po^{218}$	3.1 min
Lead	$_{82}Pb^{214}$	26.8 min
X Bismuth	$_{83}Bi^{214}$	19.7 min
Polonium	$_{84}Po^{214}$	1.64×10^{-4} sec.
Lead	$_{84}Pb^{210}$	21 yr
Bismuth	$_{83}Bi^{210}$	5.0 day
Polonium	$_{84}Po^{210}$	138.4 day
Lead	$_{82}Pb^{206}$	Stable
Thorium-232 Series		
X Thorium	$_{90}Th^{232}$	1.41×10^{10} yr
X Radium	$_{88}Ra^{228}$	6.7 yr
X Actinium	$_{89}Ac^{228}$	6.1 hr
X Thorium	$_{90}Th^{228}$	1.9 yr
Radium	$_{88}Ra^{224}$	3.6 day
Radon	$_{86}Rn^{220}$	55 sec
Polonium	$_{84}Po^{216}$	0.15 sec
Lead	$_{82}Pb^{212}$	10.6 hr
Bismuth	$_{83}Bi^{212}$	60.6 min
X Thallium	$_{81}Tl^{208}$	3.1 min
Lead	$_{82}Pb^{208}$	Stable
Potassium-40 Series		
Potassium	$_{19}K^{40}$	1.26×10^9 yr
Argon	$_{18}Ar^{40}$	Stable

1. X Isotope of particular geological or geochemical interest.

RADIOACTIVITY IN ROCKS

The most abundant rock-forming minerals that contain radioactive isotopes are the potassium feldspars and micas. The primary unstable isotope in these rocks is potassium-40. Isotopes of uranium and thorium are found in accessory minerals such as zircon, monazite, sphene, apatite and others that are not as common. These accessory minerals contribute to the radioactivity of the rock and its weathered product. They may be a part of or exceed the background radiation from the feldspars and micas. The count per second rate from potassium-40 generally predominates over the count rates from either uranium or thorium in almost all rocks except the carbonates.

Granitic and pegmatitic rocks generally contain large amounts of potassium feldspar and mica and some accessory radioactive minerals. Thus relatively high levels of radioactivity are normally found over them. Most of the uranium and thorium in igneous rocks is contained in the accessory minerals zircon, apatite, and sphene. Pyrochlore, allanite, xenotime, uraninite, and thorite are highly radioactive and are accessories, but generally they are not evenly distributed. Generally potassium, uranium, and thorium content decreases in igneous rocks as they become less felsic in composition. Mafic rocks such as basalt normally lack potassium-bearing minerals and exhibit low radioactivity. Igneous rocks that are without mica and feldspar usually have very low concentrations of potassium. Ultramafic rocks such as dunite have the lowest content of radioactive minerals and display the lowest radioactivity levels of all igneous rocks.

Metamorphic rocks may display the same degree of radioactivity as the sedimentary, igneous, or other metamorphic rock from which they were derived, except where radionuclides have been introduced or removed during metamorphism (Tables 4 and 5). Gneisses and schists have moderate-to high-radioactivity. This variability in radioactivity is due to the degree of concentration of potassium-bearing and accessory minerals present in the rock.

In sedimentary rocks such as sandstone, limestone, and non-carbonaceous shale, most of the radionuclides are in the detrital particles. Generally, with the exception of black carbonaceous shale and arkosic sandstone, sedimentary rocks are low in radioactivity. Uranium enrichment in black shale results from the affinity of organic matter for uranium.

Uranium, through weathering and erosion, is easily leached from near surface rocks and soils. Leaching is accomplished because uranium is relatively soluble in oxidizing surficial environments. Because of this solubility uranium is released by oxidation of uraninite

Table 4. Relative radioactivity of selected rocks.

Rock Type	High	Moderate	Low
Igneous	X		
granite	X		
syenite	X		
pegmatite	X		
rhyolite	X		
diorite		X	
gabbro			X
basalt			X
diabase			X
ultramafic			X
Metamorphic			
gneiss (general)	<----------	---------->	
schist (general)	<----------	---------->	
marble			X
slate			X
quartzite			X
Sedimentary			
sandstone	<----------	----------	---------->
shale	<----------	----------	---------->
carbonates (pure)			X
siltstone	<----------	----------	---------->
Sediments			
clay	<----------	----------	---------->
black sands	X		

and other reduced uranium minerals, or by breakdown of apatite, sphene, and other accessory minerals. It is transported as an ion in solution until it encounters a reducing environment, an absorbent, or precipitant (Rose, 1977). By this process uranium is redeposited in many environments.

Although uranium is soluble in nearly all oxygenated surface waters, the lower oxidation state of many ground waters limits the solůbility of uranium, especially the deeper waters in sedimentary rocks, where organic material and other reductants are present (Rose, 1977). Most surface and shallow ground waters are oxidizing and can thus dissolve uranium. The oxidizing capacity of water partially depends on the soil and rock types through which it flows and on the degree and type of topographic relief. As an example, areas of low relief, where gound waters move slowly, shallow ground waters may be reducing instead of oxidizing as previously mentioned. In most surface and ground waters, the uranium content correlates approximately with the total dissolved solids, conductivity, and bicarbonate concentration of the water (Rose, 1977).

Several uranium and thorium-bearing minerals such as zircon, monazite, xenotime and thorite are resistant to physical and chemical weathering and are not as mobile as other uranium-bearing minerals.

Table 5. Average radioelement content of rocks (Hansen, 1975).

	K^{40}ppm	Th ppm	U ppm	U/Th	Th/K^{40}	U/K^{40}
Basaltic Rocks						
average	0.8	4.0	1.0	.25	5.0	1.2
range	0.2-2.0	0.5-10.0	0.2-4.0	—	—	—
Granitic Rocks						
average	3.0	12.0	3.0	.25	4.0	1.0
range	2.0-6.0	1.0-25.0	1.0-7.0	—	—	—
Shales						
average	2.7	12.0	3.7	.31	4.5	1.4
range	1.6-4.2	8.0-18.0	1.5-5.5	—	—	—
Sandstones						
average	1.1	1.7	0.5	.29	1.5	.46
range	0.7-3.8	0.7-2.0	0.2-0.6	—	—	—
Carbonates						
average	0.3	1.7	2.2	1.3	5.6	7.3
range	0.0-2.0	0.1-7.0	0.1-9.0	—	—	—

Other more or less insoluble uranyl minerals such as carnotite, autunite, uranophane, and torbernite, do not weather easily and are found near the primary uranium deposit.

RADIOACTIVITY MAPS IN GEOLOGIC MAPPING AND EXPLORATION

Radiometric contour maps and profiles are very useful to the geologist in field investigations. Radiometric contour maps have proved valuable in correlating lithologic units obscured by weathering. They can be used to confirm or correct existing geologic maps and to extend known geologic units into unknown adjacent areas.

Faults are often identified from characteristic radioactivity patterns. Relative low count rate values over a fault zone are probably due to the weathering and leaching of the radioactive minerals in the rock. High values can occur where the rock permeability has been increased because of fracture development. The increased permeability allows for the movement of ground water and the possible deposition of radioactive minerals. The radon-222 isotope may escape through fractures in rock formations as a gas. As it does not combine with other elements to form chemical compounds, it can migrate in solution freely through pore spaces, joints, and faults. Because of its short half-life of 4 days radon-222 moves in ground water only short distances (few hundreds of feet) from its parent (radium-226). Faults can be recognized by off-set of rock units which have a contrasting radioactivity pattern.

In exploration for radioactive and non-radioactive minerals, the spectrometer has proved to be a very useful geophysical tool. The occurrence of radioactive elements in rocks and minerals can be utilized in exploration for uranium, thorium, and some types of non-radioactive mineral deposits. The presence of uranium and thorium can lead to commercial deposits of minerals containing zirconium, yttrium, rare earths, tantalum, columbium and beryllium. Uranium is a common element in phosphate deposits and thus can be used in the exploration for phosphates. The spectrometer has proved very useful in the exploration for heavy mineral deposits containing ilmenite and other economic minerals. This is due to the presence of zircon, monazite, and sphene that accumulate in placer deposits and in the heavy mineral fraction of clastic sediments. The spectrometer may also prove useful in the exploration for porphyry copper as an alteration potassium halo occurs over some deposits of this type.

REGIONAL AERORADIOMETRIC SURVEYS IN VIRGINIA

The aeroradiometric surveys flown under contract for the Division of Mineral Resources utilize a four-channel, gamma-ray spectrometer detection equipment installed in a twin-engine aircraft. During the surveys the aircraft maintains a nominal elevation of 500 feet above ground at an average air speed of 140 miles per hour. At present the surveys are flown with a crystal detector having a total volume of 452 cubic inches. Traverse and tie-line locations are drawn on 1:24,000 scale U. S. Geological Survey topographic maps for use by the navigator and/or pilot in following designated flight lines. These are spaced at one-half mile intervals. The flight path of the aircraft is recorded by a 35-mm frame-type camera. The elevation of the aircraft above ground is measured by a continuously recording radar altimeter. Fiducial markings are made on all records and camera film to be used for identifying positions. Each survey is flown with simultaneously operating analog and digital acquisition systems.

The aircraft track is established by manual identification and correlation of the 35-mm tracking camera imagery with existing U. S. Geological Survey topographic maps. The airborne data tapes are processed by computer that decodes and translates the recorded data.

After preliminary checks, corrections, and editing (both by manual and computer means) of the spectral and ancillary data, the corrected and reformatted data are further processed to remove the effects of aircraft background, and the scattering of higher energy sources into the lower energy spectral windows.

Total system background radiation is determined by eliminating the contribution of terrestrial radiation. This contribution can be determined by flights made over large bodies of water at the 500-foot survey altitude. The background count rate, determined for each of the three energy window levels for potassium, uranium, and thorium, is subtracted from the observed count that effectively compensates for the combined contribution of both cosmic radiation and aircraft background.

Compton scattering effects are compensated for by using the spectral stripping method. The stripping ratios are determined from data taken over test pads containing known amounts of radioactive materials. The corrected radiometric data is then normalized to a constant terrain clearance of 500 feet. This is accomplished assuming the absorption of gamma rays varies expodentially with altitude. The various steps involved in the data processing procedure are depicted in Figure 1.

GAMMA-RAY SPECTROMETERS DETAILS OF OPERATION

The common airborne survey instruments currently being used to detect radioactivity are gamma-ray spectrometers with crystal detectors ranging in size from 400 to more than 2000 cubic inches. The crystals used in the detector are sodium iodide activated with thallium. At present this type of crystal is the most efficient and accurate in detecting and measuring gamma radiation in airborne surveys. Survey results are normally recorded on four-channel recording systems both in an analog and digital mode. The spectrometer and accessory equipment are generally flown in twin-engined aircraft at air-speeds sufficient to obtain good survey results. The air-speed is generally determined by the volume of the crystal system.

A spectrometer by definition separates gamma radiation into two or more energy levels. The detector absorbs the gamma rays present and converts them into light pulses. The light is received by photomultiplier tubes that convert the light pulses into electrical charges and amplify them. The amplified signal is proportional to the intensity of the light pulse. Electronic circuits separate the electrical charges into several classes based on the magnitude of the charge. The result is an energy spectrum based on the gamma radiation.

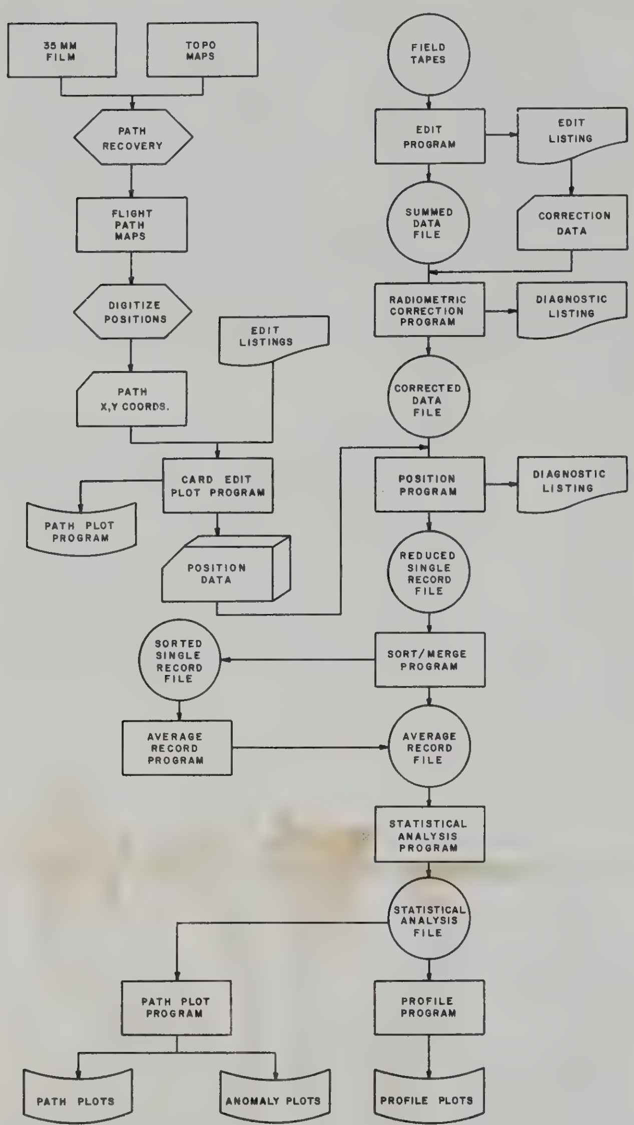

Figure 1. Data processing flow chart.

There are two basic types of spectrometers, the differential and integral. The integral type is used to measure only threshold or lower limits of a selected energy range. These spectrometers have a fixed upper limit. Where there is more than one isotope, a number of overlapping energy ranges are measured and identification is made by an indirect method of measuring the difference between energy thresholds. The differential type is used to measure the lower and upper limits of selected energy range. These spectrometers may be preset to select specific energy ranges or windows. This allows direct identification of the radioactive isotope. Where an instrument is constructed to preset several windows it is referred to as an multichannel spectrometer.

Modern airborne surveys generally use differential spectrometers with windows set for detection of the total count radiation (whole energy spectrum), and the energy levels for potassium-40 (1.37-1.57 MeV), bismuth-214 (1.66-1.86 MeV), and thallium-208 (2.41-2.81 MeV), separately.

ACKNOWLEDGEMENT

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Rose, Arthur W., 1977, Geochemical exploration for uranium, *in* Symposium on hydrogeochemical and stream-sediment reconnaissance for uranium in the United States: United States Department of Energy, Grand Junction, Colorado, p. 303-347.

NEW PUBLICATIONS AND MAPS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addresses)

List Of Publications, 1979, No charge.

Directory Of The Mineral Industry In Virginia— 1978 by P. C. Sweet, 53 p., 1979, Price $0.78 ($0.75 plus $0.03 State sales tax.)

Raw materials and mineral commodities with corresponding names and addresses of mineral producers or processors are listed. An alphabetical list of company names is included as a helpful cross index.

Radiometric Maps—Central Virginia

A detailed aeroradiometric survey was flown 1978 over central Virginia from Andersonville southward to Madisonville covering a 480 square mile area. From

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(cut along this line)

traverses about one-half mile apart at a 500-foot altitude total counts per second and individual responses of potassium, thorium, and uranium were obtained and contoured maps produced. The actual location of some rock units can be interpreted from these survey maps. They are also useful in the exploration for uranium-bearing minerals.

The survey is a portion of a continuing effort to obtain geophysical measurements of rock characteristics throughout the Commonwealth. This is particularly important where soils obscure the underlying geological formations. Two adjoining surveys are available for northern and north central Virginia.

Individual radiometric maps at the scale 1:62,500 are available as ozalids for $2.00 each. For unfolded map orders of ten or fewer maps include an additional $2.00. Order by using following numbers: 74, Charlotte Court House NW; 103, Farmville NE, NW, SW; 104, Pamplin City. A composite of these is available at the 1:250,000 scale as an unfolded mylar copy for $15.00 each. Add 4 percent State sales tax to orders with Virginia addresses.

Aeromagnetic Map Of Virginia—Overlay

This see-thru map of magnetic values can be placed over the State Geologic Map as an aid in exploring for energy and minerals deposits. Folded copies are available for $1.30 ($1.25 plus $0.05 State sales tax); for unfolded copies add $2.00.

U.S.G.S. GEOLOGIC QUADRANGLES FOR SALE

The 25 U. S. Geological Survey geologic quadrangles which depict portions of Virginia are available from the Division sales office for $1.82 each ($1.75 plus $0.07 State sales tax). These show in color the type, location, and structural position of rocks in portions of the coal-bearing area of Southwestern Virginia. Geologic maps of the Milton and Quantico quadrangles are also for sale at the same price. A listing of these publications is available upon request.

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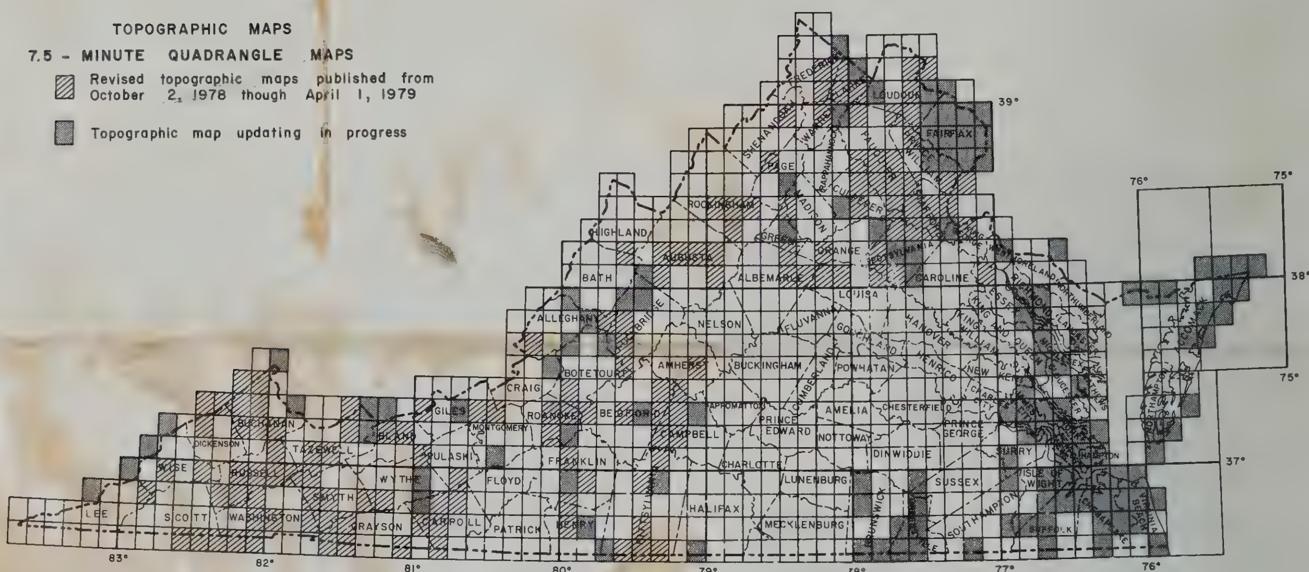

Revised 7.5-minute quadrangle maps published from October 2, 1978 through April, 1979. Each map available folded for $1.30 ($1.25 plus $0.05 State sales tax); if desired unfolded add $2.00 for orders of ten or fewer maps.

Abingdon
Alleghany
Altavista
Amherst
Arcola
Arnold Valley
Ashby Gap
Augusta Springs
Bassett
Bastian
Bedford
Belmont
Bent Mountain
Big Stone Gap
Blacksburg
Bloxom
Brandy Station
Bridgewater
Broadford
Brosville
Brumley
Carbo
Castle Craig
Catlett
Chancellorsville
Charlottesville East
Chilhowie
Churchville
City Farm
Clintwood
Coeburn
Collierstown
Culpeper
Daleville
Danville
Earlysville
Eggleston
Elk Garden
Elkhorn City
Elkton West
Elliot Knob
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Forest
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Loretto
Louisa
Lynchburg
Lynch Station
Martinsville West
Middleburg
Midland
Mt. Hermon
Natural Bridge
Newport
Northwest Eden (Spray)
Norton
Oakvale
Pittsville
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Stafford
Staunton
Stephens City
Stephenson
Stewartsville
Storck
Sylvatus
Tazewell South
Tiptop
Toms Brook
Trout Dale
Upperville
Vansant
Warrenton
Waterford
Waynesboro West
Whitetop Mountain
Winchester
Woodlawn
Wyndale

VIRGINIA MINERALS

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Richmond, Virginia

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GAMMA-RAY SPECTROMETRY AND GEOLOGIC MAPPING[1]

S. S. Johnson, T. M. Gathright, II and W. S. Henika

The Division of Mineral Resources has obtained radiometric data over parts of the Valley and Ridge, Blue Ridge, and Piedmont physiographic provinces in central Virginia. These provinces are underlain by diverse types of igneous, metamorphic and sedimentary rocks (Table 1). The Valley and Ridge province has many thousands of feet of folded and faulted Paleozoic sedimentary rocks that form northeast trending linear valleys and ridges. Sandstone, which is more resistant to erosion, makes up most of the ridges, whereas the weaker shale and carbonate rocks underlie the valleys. Rocks in this province generally have low radioactivity levels. Correlation of radioactivity and lithology is used to distinguish between major rock types, such as carbonate and shale.

The Piedmont is a province of diverse rock types with variations in amount and type of radioisotopes. It is typified by 1. complex rock structure, 2. variety of metamorphic grades, and 3. deeply weathered bedrock units covered by thick saprolite. This area is excellent for correlating geologic units by use of radiometric contour patterns.

The Blue Ridge province contains deformed Precambrian plutonic, volcanic, and sedimentary rocks, which have been folded, faulted, and metamorphosed to the greenschist facies. In addition, some metamorphosed plutonic rocks have been altered retrogressively to amphibolite and granulite facies. Identification of the many lithologic types is difficult because of the similarity of mineral composition and the gradation between different formational units. In order to identify specific rock types by radioactivity, the rock must have a higher or lower feldspar and mica content than those surrounding it.

RADIOMETRIC CORRELATIONS OF GEOLOGIC UNITS

MOUNT SIDNEY QUADRANGLE LITHOLOGIC MAP

The area depicted on the Mount Sidney quadrangle (Figure 1) is located entirely within the Valley and Ridge physiographic province. Seven geologic formations (Gathright, Henika, and Sullivan, 1978) have been grouped into three units based on the lithologic similarities of the units (Figure 1). These are divided into the Upper Cambrian Elbrook and

[1]This article is related to "Radioactivity Surveys" published in the May 1979 issue of VIRGINIA MINERALS, vol. 25, no. 2.

Table 1. Geologic formations in the Mount Sidney, Waynesboro East, and Crozet quadrangles.

AGE	NAME	CHARACTER
Quaternary	Alluvium talus, terrace deposits	Clayey sand and silt, cobbles, boulders, gravel, sand, and angular blocks.
Ordovician	Martinsburg Formation	Medium-grained, metamorphosed lithic sandstone alternately interbedded with thin-bedded, calcareous black slate.
	Edinburg Formation	Fine-grained limestone with some calcareous slate.
	Lincolnshire Formation	Medium-grained, medium - to thick-bedded limestone with chert.
	New Market Limestone	Thick-bedded, massive, micritic limestone.
	Beekmantown Group	Interbedded micritic limestone and thick-bedded, fine - to medium-grained dolomite.
Cambrian	Conococheague Formation	Fine-grained algal limestone alternately interbedded with ribbon-banded silty limestone; quartz and siliceous oolitic sand interbeds present locally.
	Elbrook Formation	Fine - to medium-grained crystalline dolomite interbedded with thin algal limestone and argillite.
	Waynesboro Formation	Argillite and phyllite with interbeds of laminated to thin-bedded dolomite and limestone, fine-grained, thin - to thick-bedded sandstone.
	Antietam Formation	Massive, fine-grained vitreous metamorphosed quartzite interlayered with laminated phyllite, argillite, and sandstone.
	Harpers Formation	Phyllite with thin to massive Interbeds of metamorphosed sandstone; quartzite and ferruginous sandstone dominant locally.
	Weverton Formation	Coarse-grained ferruginous sandstone and pebbly quartzite. Thick phyllite at base.
Precambrian	Catoctin Formation	Massive schistose metabasalt and amygdaloidal metabasalt interbedded with metasediments.
	Swift Run Formation	Schistose, metamorphosed basalt and lithic sandstone.
	Mechum River Formation	Metamorphosed sandstone, graywacke, and phyllite.
	Crozet Granite	Coarse-grained, porphyritic granite.
	Pedlar Formation	Coarse-grained, massive to sheared granodiorite gneiss.
	Lovingston Formation	Massive to foliated granite gneiss and mylonitic, augen-bearing gneiss.
	Cataclastic rocks	Mylonite gneiss.

Conococheague formations (Unit A); Middle Ordovician Beekmantown Group, New Market Limestone, and the Lincolnshire and Edinburg formations (Unit B); and Upper Ordovician Martinsburg Formation (Unit C). Quaternary alluvial deposits occur locally over all the units.

Contour patterns constructed from radiometric values obtained over this rock sequence appear to be directly related to the lithologies of the three units. The Elbrook and Conococheague formations (Figure 1, Unit A) have the highest radiometric values measured in the quadrangle. Unit A is mainly limestone and dolomite. The high counts per second may be attributed to the presence of terrigenous sediments (Figure 2A) intermixed with limestone and dolomite. Argillitic interbeds are present in the Elbrook Formation (Figure 2A) and quartz and siliceous oolite sand beds are in the Conococheague (Figure 2B). Silt layers in straticulate limestone (ribbon rock) are common to both the Conococheague and Elbrook formations (Figure 2C).

Unit B (Figure 1) has the lowest radiometric values measured in the quadrangle and is predominantly limestone and dolomite of the Beekmantown Group, the New Market Limestone, the Lincolnshire and Edinburg formations. Calcareous slate is present in the Edinburg Formation. Unit B is noted by the closed lows that dominate its contour pattern. In the central portion of the area the radiometric lows of Unit B emphasize by contrast the northeast trending linearity of Unit A. A radiometric high of 624 counts per second (northwest trend) occurs in the northeastern part of the quadrangle. This high is attributed to a middle limestone unit in the Beekmantown Group, which is spottedly exposed throughout this area.

The Martinsburg Formation (Figure 1, Unit C) displays moderate to high radiometric values when compared with units A and B. In the northwestern exposures Unit C is predominantly a slate interbedded with limestone. In the southeastern area Unit C is mainly sandstone, calcareous argillite, and slate; some interbeds of calcareous slate are present. The radiometric values displayed over the unit are related to the potassium feldspar and mica in the sandstone and heavy detrital minerals, including zircon. The northwest trend of low values in the contour pattern east of Weyers Cave occurs over alluvium in the flood plain of North River. This contour pattern is probably due to the lack of radioactive minerals in the alluvium. The closed low of 488 counts per second in the southeast occurs over a very deeply weathered area. The local high values are attributed to exposed feldspathic sandstone and argillitic beds in the Unit (Figure 2D).

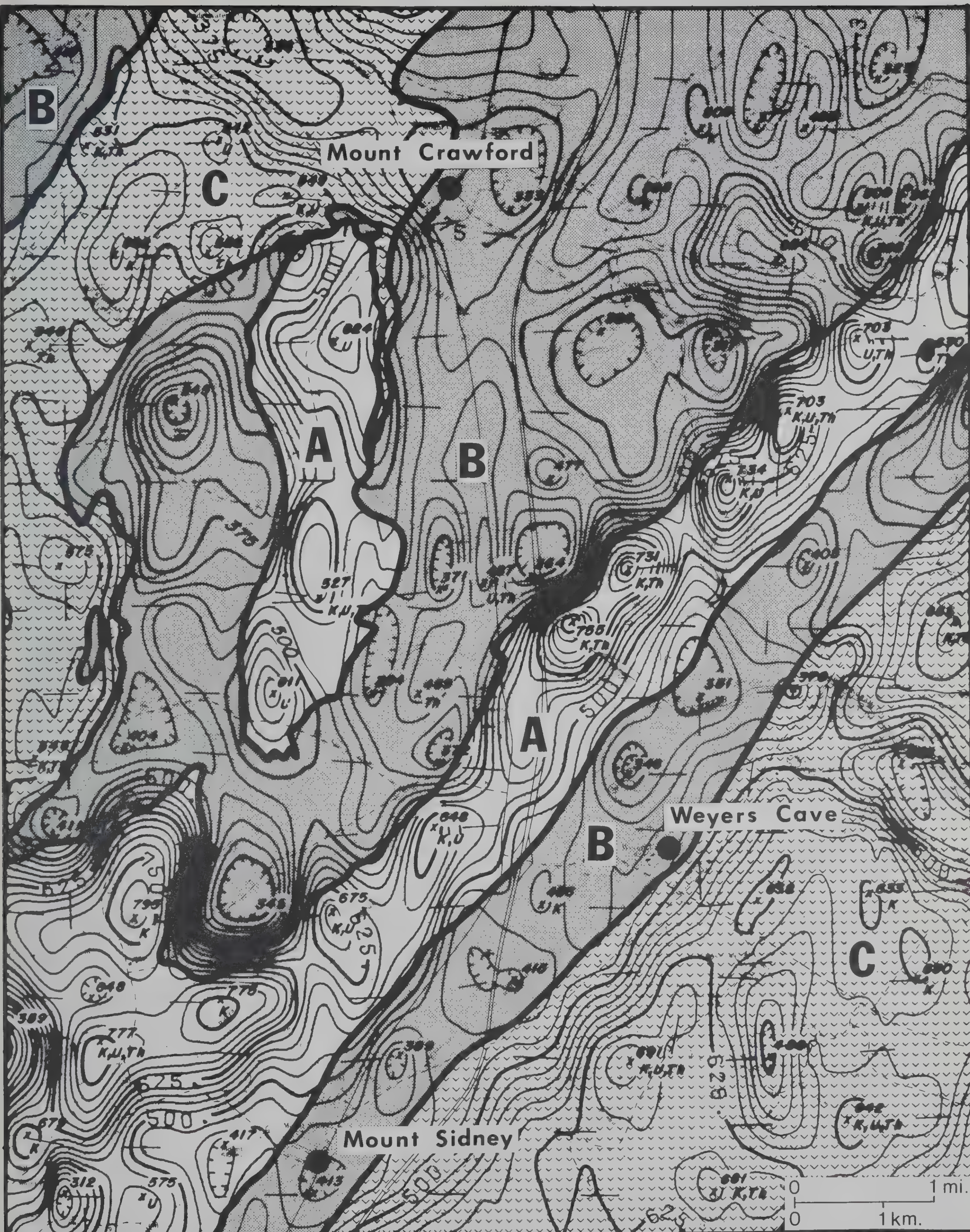

Figure 1. Generalized lithologic map of the Mount Sidney quadrangle with superposed radiometric contours. Explanation: A - Elbrook and Conococheague formations, B- Beekmantown Group, New Market Limestone, the Lincolnshire and Edinburg formations; C - Martinsburg Formation; contour interval 25 and 125 CPS; traverse spacing 0.5 mile; altitude 500 A.M.T., crystal volume 452 in³. Radionuclides: K, potassium-40; Th, thallium-208; U, bismuth-214.

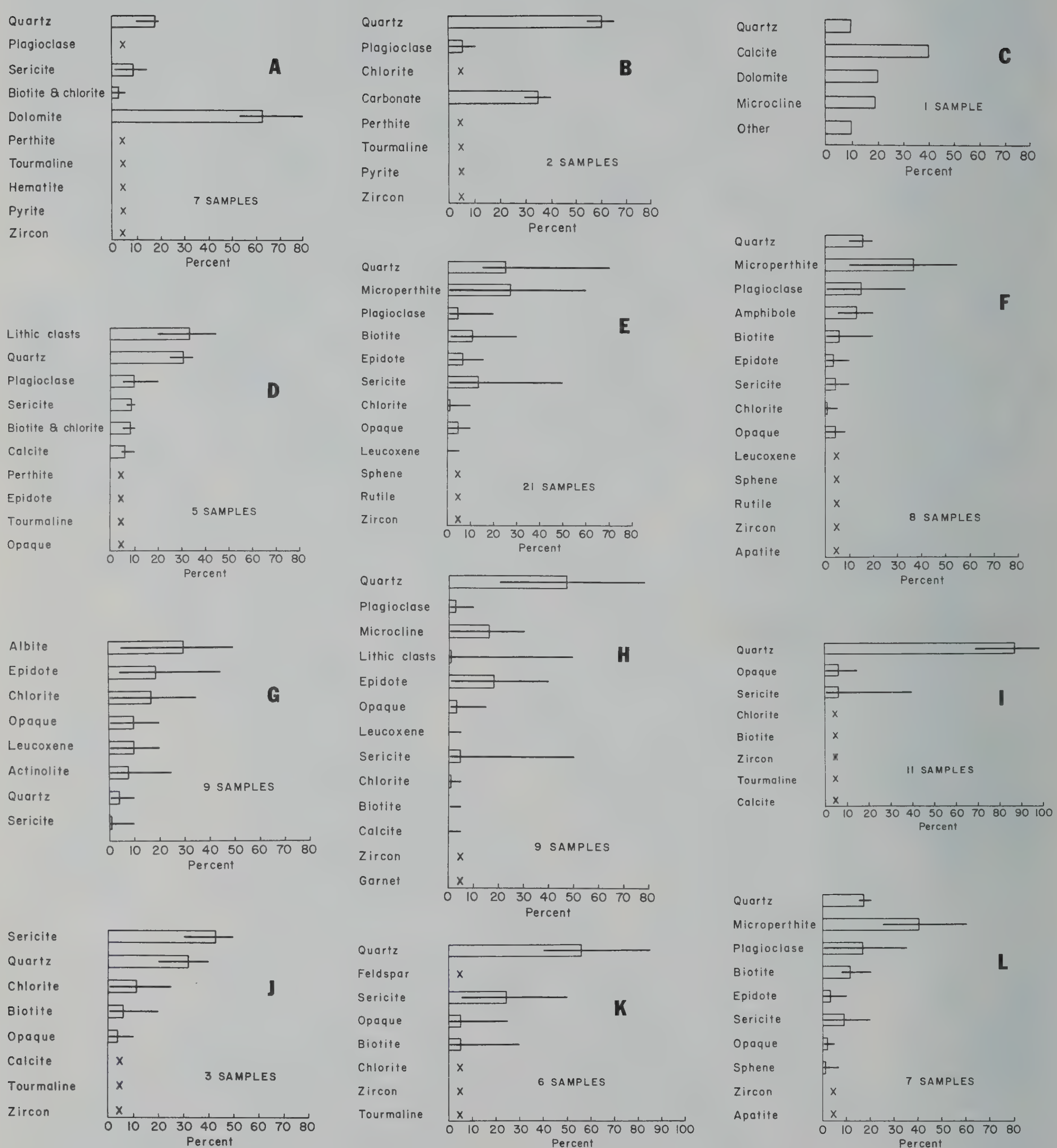

Figure 2. Mineral composition ranges (lines) and averaged estimated composition (bars) of formations in the Mount Sidney, Waynesboro East, and Crozet quadrangles. Minerals in amounts less than 5 percent indicated by X. A, argillitic interbeds - Elbrook Formation; B, sandstone interbeds - Conococheague Formation; C, silty laminae from straticulate limestone - Conococheague Formation (X-ray analyses only); D, metamorphosed lithic sandstone - Martinsburg Formation; E, cataclastic rocks; F, granodiorite gneiss - Pedlar Formation; G, metabasalt - Catoctin Formation; H, metasedimentary rocks - Catoctin Formation; I, metamorphosed sandstone - Harpers Formation; J, phyllite - Harpers Formation; K, metasedimentary rocks - Weverton Formation; L, mylonitic biotite gneiss - Lovingston Formation.

Figure 3. Generalized lithologic map of the Waynesboro East quadrangle with superposed radiometric contours. Explanation: A - Cataclastic rocks and Lovingston and Pedlar formations; B - Crozet granite; C - Swift Run and Catoctin formations; D - Weverton and Harpers formations; E - Antietam Formation; F - Elbrook Formation; contour interval 25 and 125 CPS; traverse spacing 0.5 mile; altitude 500 A.M.T.; crystal volume 452 in³. Radionuclides: K, potassium - 40; Th, thallium-208; U, bismuth-214.

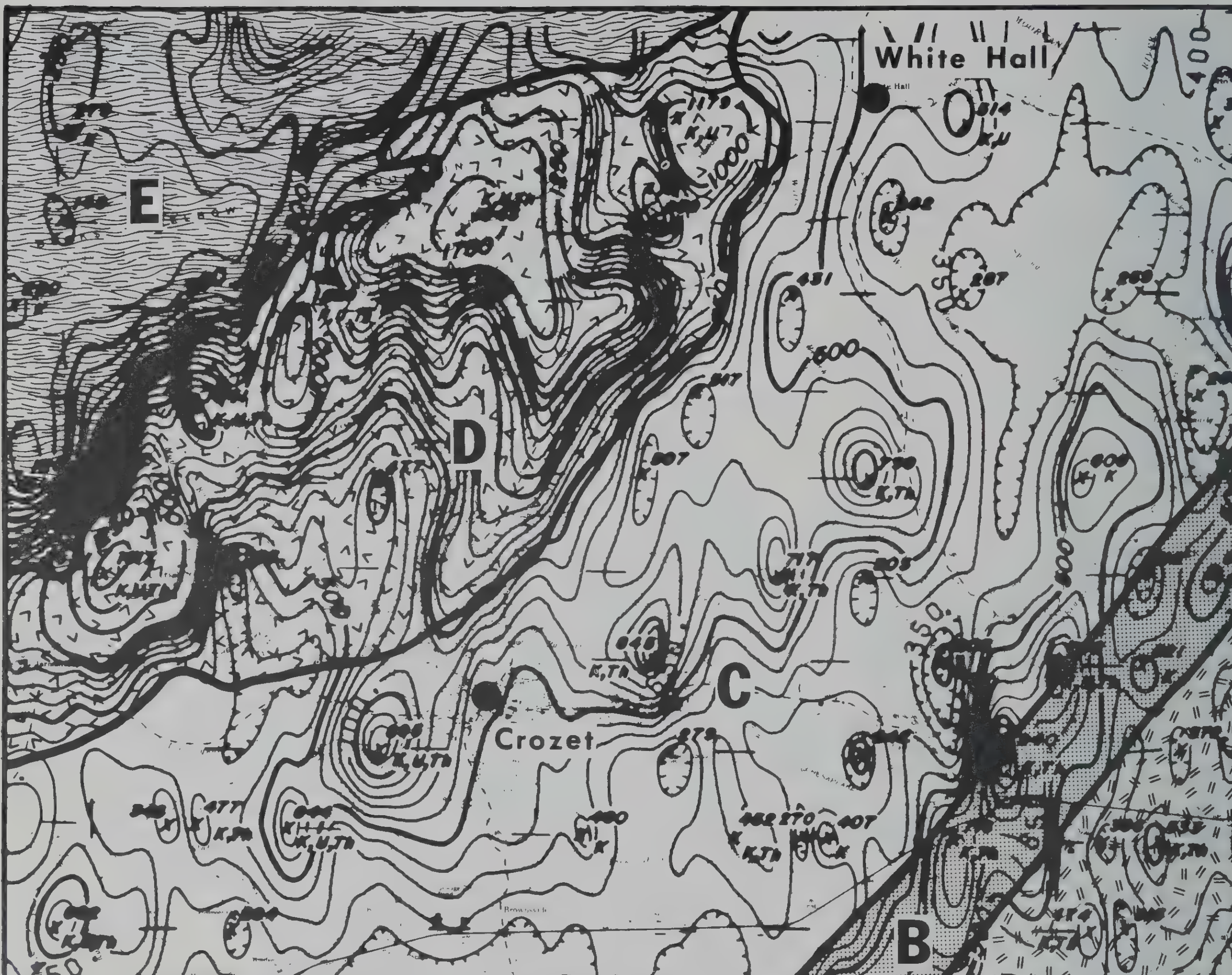

Figure 4: Generalized lithologic map of the Crozet quadrangle with superposed radiometric contours. Explanation: A - Lovingston Formation; B - Mechum River Formation; C - Pedlar Formation and cataclastic rocks; D - Crozet granite; E - Swift Run and Catoctin formations; contour interval 25 and 125 CPS; traverse spacing 0.5 mile; altitude 500 A.M.T.; crystal volume 452 in.[3] Radionuclides: K, potassium - 40; Th, thallium - 208; U, bismuth - 214.

WAYNESBORO EAST QUADRANGLE LITHOLOGIC MAP

The Waynesboro East quadrangle area is located in the Valley and Ridge, Blue Ridge, and Piedmont physiographic provinces (Figure 3). Eleven geologic formations (Gathright, Henika, and Sullivan, 1977) have been grouped into six units based on lithologic similarities of the units. These are divided into cataclastic rocks and the Lovingston and Pedlar formations, all of Precambrian age (Unit A); the Precambrian Crozet granite (Unit B); the Precambrian (?) Swift Run and Catoctin formations (Unit C); the Cambrian Weverton and Harpers formations (Unit D); the Cambrian Antietam Formation (Unit E); and the Cambrian Elbrook Formation (Unit F). Localized Quaternary alluvial deposits overlie each of the units.

The highest radiometric values in this area (Figure 3) occur over units B, D, and F; the lowest, over units C and E. Unit A is also low, but is lithologically different from units C and E. The variance in the radiometric contour patterns is attributed to the different lithologies present in the above units (Table 1). The two high value areas of cataclastic rocks in Unit A (Figure 2E) are probably composed of sheared Crozet granite (Unit B). This coarse-grained porphyritic granite has an abundance of potassium feldspar and is essentially biotite-free. Some of the Crozet granite may be intruded into the Pedlar Formation (Figure 2F; grouped in Unit A) and later both were sheared intensely.

Unit C, the Swift Run and Catoctin formations, is predominantly a metamorphosed basalt and has some of the lowest radiometric values. The small areas displaying slightly higher count rates may be due to thin, metasedimentary interbeds in the Catoctin Formation (Figure 2H) derived in part from the Precambrian granites. Unit D, the Weverton and Harpers formations, is stratigraphically higher and is a clastic sequence (Figure 2I, J, and K). The major element contributing to the radiometric values in this unit is potassium accompanied by lower values for uranium and thorium.

Unit E is composed of relatively pure quartzite of the Antietam Formation that has deeply weathered sandstone and phyllite interbeds. Detrital feldspar (less than 10 percent) and trace amounts of zircon seem to be the only radioactive-bearing minerals present and account for the low radiometric values. Talus and alluvial deposits overlie the Shady and Waynesboro formations to the west. The radioactivity of these formations is masked by the alluvial cover. The high value in the northwestern area over Unit F, the Elbrook Formation, compares favorably with the high value over the Elbrook Formation in the Mount Sidney quadrangle (Figures 1 and 2A).

CROZET QUADRANGLE RECONNAISSANCE LITHOLOGIC MAP

The Crozet quadrangle (Figure 4) has most of the lithologic units present in the adjoining Waynesboro East quadrangle. The quadrangle lies in the Blue Ridge and Piedmont physiographic provinces. The rocks mapped in reconnaissance have been grouped into five units. Those of Precambrian age are the Lovingston Formation (Unit A); the Mechum River Formation (Unit B); the Pedlar Formation and cataclastic rocks (Unit C); and the Crozet granite (Unit D). The youngest unit includes the Swift Run and Catoctin formations of Precambrian (?) age (Unit E). Localized quaternary alluvial deposits overlie each of the units. The most prominent features on the Crozet quadrangle (Figure 4) are the high radiometric values in the northwestern area of the map and the northwest trending high in the southeastern portion of the map. The highest radiometric value occurs over the Crozet Granite (Unit D), which is a coarse-grained porphyry. Unit D can almost be mapped solely on its radiometric contour pattern. The high values of Unit B occur over rocks in the Mechum River Formation, which includes metamorphosed arkosic sandstone, graywacke, and phyllite.

The Lovingston Formation (Unit A) is mainly a medium-to coarse-grained granite gneiss with some mylonitic, augen-bearing biotite gneiss. The radiometric values over this formation are variable with local highs and lows (Figure 2L). Cataclastic rocks (Unit C) are largely derived from the shearing and deformation of the Lovingston Formation. Undeformed gneiss (Unit A) of the Lovingston Formation is difficult to distinguish from the cataclastic rock because of similarity in mineral composition. Unit E, the Catoctin Formation displays the same low values as discussed in the Waynesboro East quadrangle.

The contrast between radiometric values of rock types provides a means to correlate these types in much of the study area. From this study it was determined that radioactivity data is a useful aid to geologic mapping in the Valley and Ridge and Piedmont provinces in Virginia.

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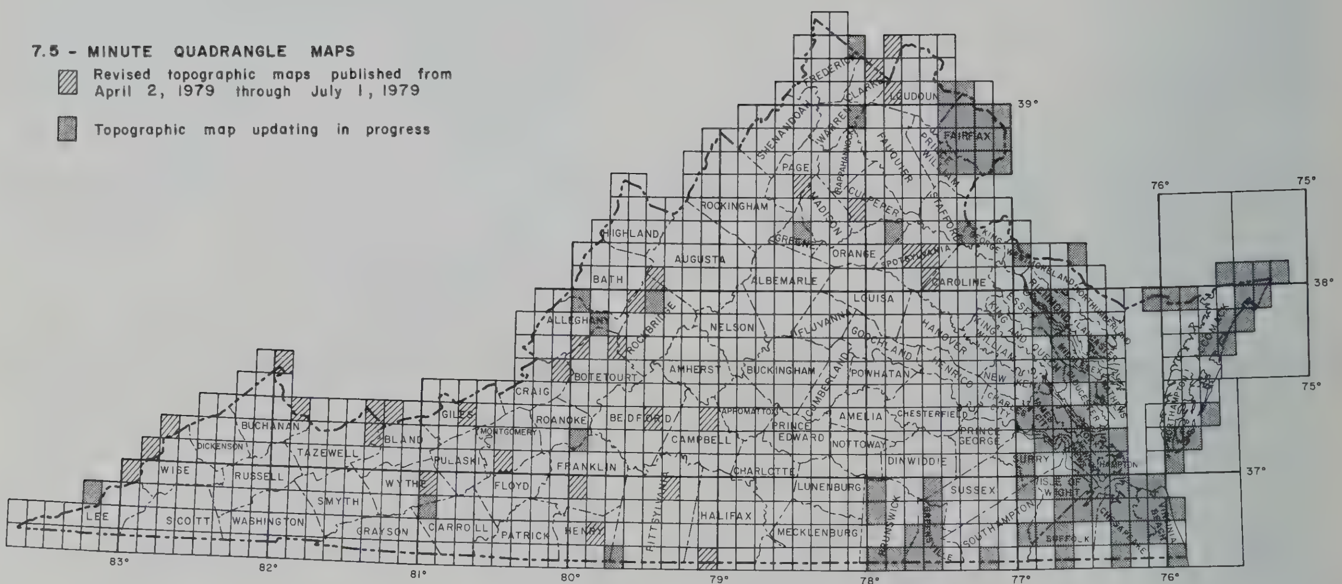

Revised 7.5 - minute quadrangle maps published from April 2, 1979 through July 1, 1979. Each map available folded for $1.30 ($1.25 plus $0.05 State sales tax); if desired unfolded add $2.00 for orders of ten or fewer maps.

Alton
Benham
Berryville
Big Meadows
Bluefield
Bluemont
Bradshaw
Bramwell
Brokenburg
Cave Creek
Charlestown
Craigsville
Culpeper, W.
Goode
Gretna
Jenkins W.
Ladysmith
Martinsville East
Max Meadows
Millboro
New Castle
Pearisburg
Riner
Rocky Mount
Rustburg
Spotsylvania
Strom
Sugarloaf
Warncliffe
Whitesburg

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MINERALS AND FUELS IN THE 1980's AND 1990's

It is apparent as we enter the final two decades of the 20th Century that the applied geological sciences are experiencing a rebirth. Geologists are needed not only for their classical roles in exploration and production of earth raw materials, but also in the areas of waste disposal, identification of geological hazards, and for land-use planning and development.

The past experience of most of use in this country is one of an expanding economy and generally increasing standard of living, in spite of moderate but persistent population increases. This pattern of growth and expansion was shaken in 1973 by the first Arab oil embargo, when the United States was rudely reminded for the first time since World War II of the dangers of dependence upon foreign suppliers. Since that embargo, and largely because of persistent uncertainties about availability of foreign fuel supplies, the economy has developed exaggerated inflationary tendencies which have not existed since the days following the World War II - Korean War era. It is inevitable that standards of living will decrease as ever increasing world populations apply greater and greater pressures on our finite natural resource base and upon the life support system of the planet.

One of the prime goals of the developed, industrialized world during the remaining decades of this century and in the next century will be the avoidance of an India syndrome. The India syndrome — a large population mass, with most people living at a very low standard of living and with each person allotted only a small share of meagre and ever declining resources — has engulfed much of the world as modern sanitation and medicine have reduced the effects of yesterday's pandemics. The India syndrome can perhaps be avoided by stabilization or, more certainly, by a moderate decline in the world's population — a condition that is not likely to be achieved in the near future.

It is the purpose of this paper to point out some of the problems which our society must consider as it attempts to fulfill its needs for energy and minerals and at the same time to avoid the adverse effects that these activities impose upon the natural environment. In addition, we will attempt to relate the programs of the Division to these problems as it strives to meet the needs of the Commonwealth.

THE NATURAL ENVIRONMENT
THE LIFE SUPPORT SYSTEM

The life support system of the planet is built upon an extremely intricate interrelationship of organisms, plants and animals, with their natural physical and

chemical surroundings — light, heat, soil, water nutrients, etc. On a worldwide basis the composition of the planet's surface, the mother earth and its atmosphere, has changed slowly over a time span measured in hundreds of millions, even billions, of years. Since the creation of the organic world, life forms have generally increased in complexity as they were preferentially selected by long-term changes in the natural environment. This diversity insures continuity of life on the planet, because as some forms become troubled and then extinct during the evolutionary process, others are there to occupy abandoned ecological niches.

During periods of natural disasters, some local, others worldwide, the existing biota does not have time to evolve, resulting in either local or worldwide extinctions and a temporary decrease in diversity of life forms. Natural disasters, such as earthquakes, local changes of sea level and volcanic explosions are common in our life times and cause local ''kills'' of life. Worldwide climatic changes, such as those during the recent ice ages, resulted in widespread extinctions which are well documented in the geologic past.

In many ways man is a natural catastrophic disaster whose activities cause numerous extinctions both on a local and on a worldwide basis. His adverse activities have generally resulted in a worldwide decrease of biotic diversity; i.e., in a general homogenization of life on earth.

DESTRUCTION OF LAND

The continuing increase in man's population, with concurrent industrialization, is placing a tremendous strain upon the life support system of this planet. Urban and suburban sprawl are removing millions of acres of land from productivity for the foreseeable future, creating man-made deserts populated only by people, dogs, cats, rats and pigeons. In contrast, mining only temporarily decreases biologic productivity, until mined sites are reclaimed by nature with or without man's help.

WASTE DISPOSAL

Today's modern societies have severe problems regarding the handling and disposal of wastes, both municipal and industrial. The difficulty in obtaining suitable landfill sites plagues many American communities. Burial of wastes must be accomplished both with a minimum of esthetic impact upon local communities and with a minimum of damage to the shallow geologic environment, particularly with regard to the escape of leachate into nearby ground and surface waters. The disposal of industrial wastes, in particular those which are radioactive, hazardous or highly toxic, is a problem of increasing importance. Recent events have shown that dumping of these substances into rivers or estuaries (James River) or burial of drums of hazardous and toxic materials (Love Canal) can cause long-lived and far reaching damage, threatening the life and health of human populations, as well as those of other species. Furthermore, introduction of liquid wastes into deep geologic strata can cause disruptions, such as local seismic activity, as stress fields in the earth are changed. Almost all of these chemicals or radioactive substances are unnatural or exist naturally in such small quantities that biota has not generally developed tolerant varieties. However, even poisons can be overcome by nature if time permits organisms to develop resistant strains, as some insects have in their fight to survive against pesticides.

FUEL POLLUTION

All fossil fuels produce carbon dioxide and particulate matter upon burning, which, as they accumulate in the atmosphere, may cause long-range climatic changes. Particles tend to scatter sunlight, thereby reducing the energy incident on the earth. In contrast, accumulation of carbon dioxide in the atmosphere may result in a greenhouse effect, thereby increasing surface temperatures and causing the melting of polar ice caps. In addition, nitrogen and sulfur compounds emitted from tall smoke stacks have produced notably acid rains which have a particularly deleterious effect upon the biota in non-carbonate terrain, where acids persist unneutralized in near-surface environments. Automobiles produce noxious emissions which accumulate and linger close to the ground, especially when certain climatic conditions persist over prominent topographic basins. Nuclear power plants do not produce the noxious oxides and acids which result from burning fossil fuels, but instead produce long-lived, hazardous radioactive wastes. The only clean power sources available to us are from the sun, either directly, or indirectly as wind and water power, and from high temperatures in the earth - solar and geothermal - but these by their very nature can be exploited economically only in certain areas. Table 1 summarizes the characteristics of common energy sources.

Table 1. An analysis of existing energy sources.

ENERGY SOURCE	ADVANTAGES	DISADVANTAGES	FUTURE	ACTION REQUIRED
Petroleum	Refined to a variety of liquid and gaseous fuels; petrochemical industry; easily produced, transported, stored.	Air pollutant when burned, contributes nitrous oxides, sulferous oxides, and carbon dioxide to atmosphere; carbon dioxide promotes greenhouse effect.	Increasing demand and costs; declining reserves and production; will become uneconomic as fuel in 21st Century.	[1] Conservation through mass transit, decreased use of automobile; development of tar sands, and oil shales; secondary, tertiary recovery in old oil fields.
Natural Gas	Easily produced, transported and stored, generally clean burning.	Contributes primarily carbon dioxide to atmosphere; promotes greenhouse effect.	Increasing demand, and costs; declining reserves and production; volume produced will progressively decrease in 21st Century.	[1] Development of shale gas; methane from coal beds; improvement of methods of transportation from remote sources.
Coal	Abundant, easily produced, transported and stored.	Air pollutant when burned; contributes nitrous oxides, sulferous oxides, carbon dioxide to atmosphere; carbon dioxide promotes greenhouse effect. Source of acid rain when gasses vented through tall stacks. Temporary impact on mined land.	A primary source of energy during 21st Century, will be converted to liquids, gasses.	[1] Development of liquefaction, gasification plants, improvement of technology for removing wastes from smoke stacks prior to emission.
Hydroelectric	Reliable source of cheap electric power; once installed will generate power for a long period of time with minimum maintenance. Nonpolluting, renewable.	Requires flooding of large areas of prime farmland.	Renewable source of electric energy.	[1] Development of remaining potential high-head reservoirs; development of low-head reservoirs; development of tidal power plants.
Nuclear reactors	Reliable source of cheap electric power; does not contribute to air polution, or greenhouse effect.	Produces long-lived radioactive wastes; possible source of illicit nuclear weapons.	Short-term (25 years) supply of uranium available for fuel.	[1] Development of fool proof methods for storage of wastes; protection of fuel. Improve nuclear-power plant safety.
Geothermal	Reliable, long-lived source for hot water (low temperature geothermal) and/or steam (high temperature geothermal); generally non-polluting.	Site-specific, requiring local geothermal source and water. Fluids produced may be corrosive.	Will be widely developed in suitable areas.	[1] Identification of geothermal sources.
Solar	Reliable, non-polluting, renewable.	Seasonal and geographic restrictions.	Solar power will ultimately replace petroleum, natural gas, and coal for space heating, electrical power generation.	Develop solar technology.
Biomass	Reliable, non-polluting, renewable.	Land currently used for other purposes will be diverted to producing fuel-producing crops. Food grains will be diverted to producing alcohol.	Ultimate source for hydrocarbons to be used as solid, liquid or gaseous fuel.	Identify, develop and grow organisms suitable for fuel or as a source of fuel.

[1]Requires major input from geological sciences.

MINERALS AND FUELS

Mineral resources, including mineral fuels, metallic ores, and non-metallic materials, vary individually in abundance and geographic distribution in the earth's crust. These resources are non-renewable and, although useful deposits may range from small to very large, all of the materials are finite in amount. Because of the unequal distribution of mineral resources throughout the world, nations have varying degrees of self-sufficiency in the materials that they need. Certain countries have been richly endowed by nature whereas others have very limited resources. The United States is fortunate in having adequate quantities of some resources, such as coal, because of both the diversity of its geology and its extensive area, but is dangerously deficient in others.

FOREIGN FUEL DEPENDENCE

During periods of peace and political stability, international trade in mineral commodities provides nations, including our own, with the required mineral raw materials. When normal patterns of supply are interrupted or changed by wars, political unrest, changing national alliances, embargoes, nationalization of production, or other factors, however, the consequences have a profound impact. The United States has become increasingly dependent upon foreign sources for many of its raw materials. One aspect of foreign dependence is being dramatically demonstrated by our reliance upon OPEC nations for much of our oil supply. During the first half of 1979, for example, about 22.5 percent of the energy consumed in the U. S. was supplied by imported oil which was purchased at ever-escalating prices, causing large deficits in our world trade balance.

OIL AND NATURAL GAS

Our nation's attention has been focused in recent months on the current oil shortage and the change in the American lifestyle that will likely be the result. The problems of decreasing domestic reserves and increasing costs for imported petroleum have been made real to the public by long lines at service stations and higher prices for gasoline, heating oil, diesel fuel, jet fuel, and numerous other petroleum-based products. Domestic oil production peaked in 1973 and world crude oil production showed almost no change between 1977 and 1978. This indicates that economic expansion must be based on conservation and wiser use of petroleum as we develop and switch to other energy sources. The petroleum supply in the U. S. from 1930-1977 is shown by Figure 1. Similarly the public is becoming more aware that natural gas is a non-renewable energy source that is ultimately limited in quantity, and that it will be increasingly more expensive to industrial and residential consumers. The confusion and discomfort created by even a brief interruption of electrical service, and the possibility for large-scale "brownouts" in the future, serve to emphasize what may occur if adequate fuel sources for the generation of electric power are not available. The many problems associated with depletion of our oil and gas, and the activity needed to change the country's energy-base to other more-plentiful sources such as coal and solar energy will call for a great national effort in planning, manpower, capital, and materials. The need to make this effort, however, is beyond question.

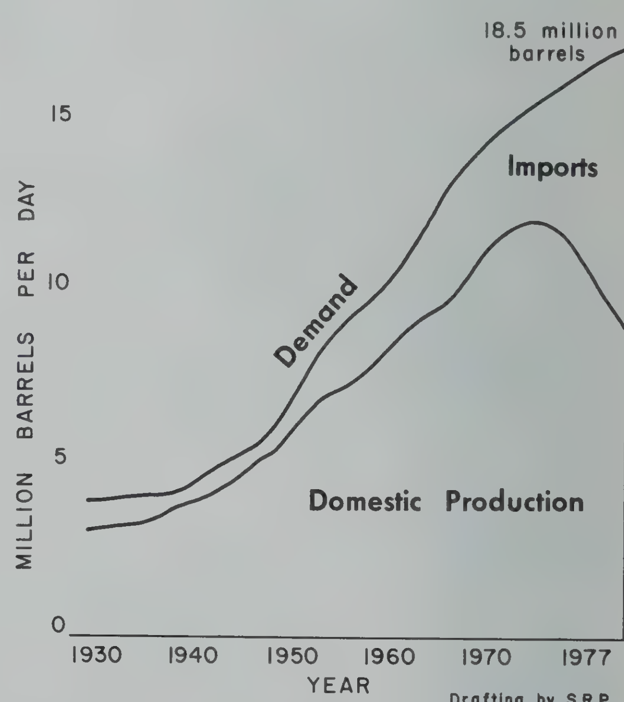

Figure 1. The petroleum supply in the United States from 1930-1977 (Gulf Oil Corporation, 1979).

NONFUEL MINERALS

The public is hardly aware, however, of the less-publicized but equally grave situation that confronts the United States with regard to other mineral supplies. Simply stated, the nation does not have sufficient, known domestic supplies of many nonfuel mineral commodities to meet all of our future needs. The economy and security of the U. S. are based

largely on a wide range of mineral resources, including the energy resources previously discussed. The U. S. Bureau of Mines (1978) reports, for example, that over 21,000 pounds of new nonfuel mineral materials, including metals and nonmetals, are required annually for each American; in 1977 the total use of new nonfuel mineral supplies in this country was about two billion tons. Approximately 100 nonfuel mineral commodities are used for industrial and agricultural purposes. As our population grows, the demand for products and activities based on these mineral supplies will also grow dramatically. If we are to sustain our standard of living and national security the country must be assured of adequate supplies of these materials in the future. Under present conditions there is no such assurance.

Foreign Mineral Dependence

The United States has large reserves of some resources such as phosphate rock, stone, and sand and gravel. Domestic production of numerous other materials such as iron ore is augmented by imports to meet levels of consumption. Our requirements for still other commodities, some of strategic importance, are entirely or almost entirely dependent upon imports from foreign countries. The U. S. has an uncertain relationship with some of these countries. The nation's net import reliance for selected commodities, as analyzed by the U. S. Bureau of Mines (1978) in a report entitled "Status of the Mineral Industries," is shown in Table 2. This report notes that net imports supply more than 50 percent of our consumption of 18 major nonfuel commodities. Imports provide from 85 to 100 percent of the U. S. consumption of certain vital materials such as columbium, cobalt, manganese, platinum-group metals, bauxite, chromium, and sheet mica.

A major danger to the U. S. is that supplies of many critical minerals that must be imported are becoming less secure. Many materials are imported from nations that are subject to increasing political instability or are our ideological adversaries, making long-term mineral prices and availability uncertain. In a study entitled "Report on Issues Identified in the Nonfuel Minerals Policy Review," prepared for the White House (1979), it is noted, for example, that the United States would be dependent upon the Soviet Union for chromium and platinum-group metals if present supplies from South Africa should become unavailable. One has only to recall the shortages of certain key materials during World War II also, and the desperate attempts made to transport these materials over long distances under wartime conditions to realize the potential danger to the U. S. in import dependence. For this reason, the Federal Government maintains stockpiles of many strategic materials, including mineral commodities, as a partial solution to our import vulnerability.

Mineral Industry Problems

Our domestic mineral position has been adversely affected by many problems in recent years. The American mineral industry is increasingly affected by inflation and higher costs for labor, equipment, services, and transportation and more recently by requirements for meeting the numerous environmental standards. This increased cost of doing business serves to limit the amount of capital available for the exploration and development of new deposits and for the modernization and expansion of production facilities. In some cases high costs have forced the closure of less profitable operations that nevertheless contributed to our mineral supply. Many operations have been shut down because of large investments that would be needed to bring them into compliance with air, water, or other environmental regulations. The higher costs make the existing industry less able to compete with foreign sources of materials. Some of these sources are subsized by their respective governments for economic or political purposes. In addition, the depletion of many of the higher-grade or more easily accessible deposits that were mined in the past in the U. S. has necessitated, in some cases, the use of lower grade or more distant materials, often with an accompanying increase in costs, energy requirements, and adverse environmental impact.

The location, evaluation, and development of new sources of materials is a basic activity of the mineral industry. These efforts are often extremely costly and time-consuming. Lead times of many years and the expenditure of millions of dollars may occur before a new mine or plant is brought into production. For example, new synthetic fuel plants may take from 4 to 8 years from the time a decision is made to build such a facility until first production is achieved. Prospective sites from which useful mineral materials might be obtained are increasingly precluded from such activity by competing land uses, high land values, or zoning restrictions. In many areas, materials are rendered physically inaccessible by human development such as urban or industrial growth; in essence they are "paved over." For example, deposits of sand and gravel have been covered by suburban growth in northern Virginia, resulting in the need to transport needed construction materials from more

Table 2. U. S. net import reliance of selected minerals and metals as a percent of consumption in 1977 (U. S. Bureau of Mines, 1978).

MINERALS AND METALS	NET IMPORT RELIANCE* AS A PERCENT OF APPARENT CONSUMPTION** (0% – 25% – 50% – 75% – 100%)	MAJOR FOREIGN SOURCES (1973-1976)
COLUMBIUM	100	BRAZIL, THAILAND, NIGERIA, MALAYSIA
MICA (sheet)	100	INDIA, BRAZIL, MALAGASY REPUBLIC
STRONTIUM	100	MEXICO, SPAIN
MANGANESE	98	BRAZIL, GABON, SOUTH AFRICA
TANTALUM	97	THAILAND, CANADA, AUSTRALIA, BRAZIL
COBALT	97	ZAIRE, BELG.–LUX., NORWAY, FINLAND
PLATINUM – GROUP METALS	91	SOUTH AFRICA, U.S.S.R., U.K.
BAUXITE & ALUMINA	91	JAMAICA, AUSTRALIA, SURINAM, GUINEA
CHROMIUM	91	SOUTH AFRICA, U.S.S.R., TURKEY, SOUTHERN RHODESIA
ASBESTOS	85	CANADA, SOUTH AFRICA
TIN	82	MALAYSIA, THAILAND, BOLIVIA, INDONESIA
FLUORINE	81	MEXICO, SPAIN, ITALY, SOUTH AFRICA
NICKEL	70	CANADA, NORWAY, NEW CALEDONIA, DOMIN. REP.
POTASSIUM	63	CANADA, ISRAEL
GOLD	61	CANADA, SWITZERLAND, U.S.S.R.
ZINC	57	CANADA, MEXICO, AUSTRALIA, PERU
TUNGSTEN	52	CANADA, BOLIVIA, PERU, THAILAND
CADMIUM	51	CANADA, AUSTRALIA, BELG.–LUX.
IRON ORE***	48	CANADA, VENEZUELA, BRAZIL, LIBERIA
IRON & STEEL SCRAP	(-14) NET EXPORTS	
MERCURY	45	SPAIN, ALGERIA, MEXICO, YUGOSLAVIA
SELENIUM	42	CANADA, JAPAN, MEXICO, YUGOSLAVIA
BARIUM	38	PERU, IRELAND, MEXICO
TITANIUM (ilmenite)	37	CANADA, AUSTRALIA
SILVER	36	CANADA, MEXICO, PERU, U.K.
GYPSUM	36	CANADA, MEXICO, JAMAICA, DOMIN. REP.
VANADIUM	35	SOUTH AFRICA, CHILE, U.S.S.R.
ANTIMONY	21	SOUTH AFRICA, P.R. OF CHINA, BOLIVIA
IRON & STEEL PRODUCTS	15	JAPAN, EUROPE, CANADA
COPPER	13	CANADA, CHILE, PERU, ZAMBIA
LEAD	13	CANADA, PERU, MEXICO, AUSTRALIA
SALT	8	CANADA, BAHAMAS, MEXICO, NETH. ANTILLES
ALUMINUM	7	CANADA.
SULFUR	6	CANADA, MEXICO
CEMENT	6	CANADA, SPAIN, NORWAY, BAHAMAS
PUMICE & VOLCANIC CINDER	6	GREECE, ITALY

*NET IMPORT RELIANCE = IMPORTS-EXPORTS + ADJUSTMENTS FOR GOV'T AND INDUSTRY STOCK CHANGES

**APPARENT CONSUMPTION = U.S. PRIMARY + SECONDARY PRODUCTION + NET IMPORT RELIANCE.

***SUBSTANTIALLY HIGHER THAN NORMAL DUE TO STRIKES

distant areas. Many potential deposits have been lost to future use by zoning or other land-use restrictions that preclude production of minerals or do not recognize their existence. Numerous deposits that might contribute to our mineral adequacy will not be utilized because of federal, state, or local environmental restrictions that discourage or prohibit mineral activities. Removal by the federal government of vast tracts of public land from mineral exploration or production activities has restricted the area in which we can search for and inventory the Nation's resources and has reduced our short-term potential supply of usable mineral materials.

Insuring Adequate Supplies

Adequate supplies of mineral resources must be available to the United States if we are to sustain the activities of our industrialized society and the well-being of our citizens. To meet this challenge, government and industry must formulate enlightened and realistic mineral policies to plan for and supply our long-range mineral needs. These policies should provide for the optimum development of our domestic resources but should be consistent with appropriate environmental practices. In order to establish a high degree of mineral independence, domestic mineral activities should be coordinated with sound import and stockpile practices for materials that cannot be supplied from within the United States or replaced by substitutes. Development and use of substitute materials to take the place of scarcer or more costly commodities should be pursued as a major research goal. Widespread, integrated conservation programs that involve both the recycling of industrial products and the repair rather than replacement of durable goods should be a basic cornerstone of our mineral policy.

The acquisition of basic knowledge through geologic field and laboratory studies and a continuing inventory of our known mineral resources should be accelerated. Exploration activities for minerals should be encouraged and techniques for locating and evaluating new sources of materials should be improved. As the most plentiful and highest-grade materials are consumed, our extractive and processing capabilities must be increased to permit the use of lower grade materials that are below today's economic or technologic limits. The practice of sequential land use should be encouraged. This concept provides for extraction of useful minerals where practical, followed by appropriate reclamation, before land is used for other purposes.

Various levels of governmental authority should recognize the need for appropriate mineral-resources development when land-use or other plans that affect resources are formulated. Because technology, markets, and mineral requirements are not static but change continually, land-use planning should provide for periodic re-evaluation and flexibility so that changing national needs may be met.

DIVISION OF MINERAL RESOURCES

In order to meet some of the mineral and fuel needs of the future, the Division of Mineral Resources has ongoing programs in the areas of geologic and topographic mapping, fossil fuels, mineral resources, geophysics, geochemistry, and in environmental geology. In general, the Division generates basic geologic, mineral, and topographic data through its research programs, collects and organizes data provided by other government agencies, educational institutions and industry, and disseminates geologic data through its publications and contacts with a wide variety of clients.

The primary method of collecting geologic data is through field work, both detailed quadrangle mapping and regional reconnaissance of large areas. In order to perform this function the Division has three mapping sections, one each in the Coastal Plain, Blue Ridge-Piedmont and in the Valley and Ridge. Experts in each of these areas comb the countryside for outcrops, and where necessary drill to bedrock to obtain samples. Detailed mineral resource inventories are made of the areas mapped. The geologic data are compiled for each quadrangle, and maps and reports are prepared for the areas studied.

Because of the increasing importance of fossil fuels the Division is currently conducting an inventory of the coal resources of the State, in cooperation with the U. S. Geological Survey. This program will lead to new estimates for coal resources by coal bed and county. Coal samples are being obtained and detailed analyses are made by the U. S. Geological Survey, and the U. S. Bureau of Mines. The Division maintains a file of oil and gas wells in the State, and is currently compiling this information in a form amenable for publication and computerization so that the data will be more generally available to the public and industry. Sets of drill cuttings from numerous oil and gas tests in the State are on file and available for study by interested geologists. The Division is working with the Department of Mining and Mineral Engineering at Virginia Tech, evaluating

the possibilities of producing methane from unmineable coal beds. The Division is also making studies of earth lineaments in southwestern Virginia and their relationship to occurrences of oil and gas.

In the area of nonfuel mineral resources the Division is working on a project to computerize its mineral resource data and incorporate it into the U. S. Geological Survey CRIB system. At a future date the Division will develop its own computerized mineral resources data bank which will be specifically tailored to the needs of the State. The Division is evaluating specific non-metallic and metallic mineral resources, such as clay-materials for ceramic purposes, sandstone and quartzite for high-silica products, and is preparing inventories of sulfide occurrences and other metallic mines and prospects. In past years the results of many similar studies of other commodities were published. In addition, the Division maintains files on a large volume of unpublished mineral resource information which is made available to its numerous clients.

Geophysical projects, studies of the gravity, magnetic field, and radioactivity of the State are performed both by means of contracts to geophysical companies and by detailed ground surveys by Division personnel. These different types of geophysical data are used to help interpret geologic data, locate and identify mineral prospects and to provide general information about the structure of the earth. In addition, the Geophysical Section maintains two seismic stations, a three-component station at Charlottesville and a vertical-component station at Front Royal. These are integrated into the Virginia Seismic network which is operated primarily by the Department of Geological Sciences at Virginia Tech. Also, data from the two stations are made available to the National Earthquake Information Service (USGS), Boulder, Colorado.

The Laboratory section of the Division performs numerous analyses on rocks and minerals in support of the geological mapping and mineral resources projects. In addition, laboratory personnel are currently studying a wide range of topics, such as the occurrence of massive sulfide deposits, radioactivity, stream sediment geochemistry, compositions of rocks and minerals, the occurrences of maganese and tin, and environmental problems related to mining. Studies such as these provide industry with general information which they can use in their own mineral resource programs.

The Division's Information Services section provides the public with geologic and topographic information about the State. The section works with educational institutions and groups interested in the geology and topography of the State, either at the Division's offices, or by visits and exhibits prepared for specific events. The topographic mapping program lies within the purview of the section. Virginia is one of a few states completely mapped with modern 7.5-minute topographic quadrangles (scale 1:24,000). The topographic mapping program is in cooperation with the U. S. Geological Survey. At present the emphasis of the program is in the revision of existing quadrangles on a five year basis and in obtaining a new series of intermediate-scale county base maps at a scale of 1:50,000. Whereas detailed quadrangle maps are ideally suited for a wide variety of field-oriented studies, the intermediate-scale maps are more suitable for regional compilations of mineral resources and fuels data and for planning at the county level.

Part of the Information Services Section's responsibility lies in the general area of environmental geology and land-use planning. Local and regional planners are informed about the mineral potential of their areas of interest and they are informed about geologically related natural hazards such as landslide prone areas and areas underlain by karst which may be subject to subsidence. As time and money permit, land-use maps are prepared and published, for example the recently published land modification map of Warren County.

Finally, the Division's activities result in a considerable publication effort that requires the work of draftsmen and a geologic editor. The Division maintains a rock, mineral and fossil "library" or repository which contains scientific samples collected over the years. In addition, a geologic library of over 4,000 volumes is maintained for use both by the Division's staff and by the public, in general.

R. C. Milici
D. C. Le Van

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Gulf Oil Corporation, 1979, Some useful facts on energy: 60 tables.

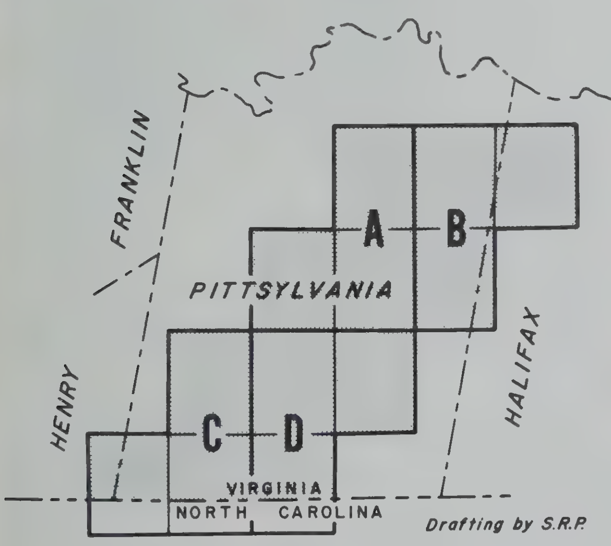
U. S. Bureau of Mines, 1978, Status of the mineral industries: 39 p.

RADIOMETRIC MAPS - DANVILLE AREA

An aeroradioactivity survey that covers approximately 600 square miles in parts of Henry, Halifax, and Pittsylvania counties is now available from the Virginia Division of Mineral Resources. The survey covers the southern three-fourths of the Virginia portion of the Daville basin. The results are presented on four separate maps, each at a scale of 1:62,500.

The survey was flown at 500 feet above terrain in an east-west direction with flight lines spaced one-half mile apart. A gamma-ray spectrometer with a 1000 cubic inch crystal system was utilized to record the total counts per second as well as the individual responses of potassium, thorium, and uranium. Radiometric maps are useful in determining the distribution of rock types, especially where they are covered by soil, and in locating of possible uranium occurences.

Maps may be ordered by 15-minute-area name (see illustration). These are available as ozalid copies for $2.08 each from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903. A composite mylar copy is also available for $15.60. Prices include 4 percent State sales tax.



A - CHATHAM 15′ RADIOMETRIC MAP (Covers Gretna, Chatham, and Spring Garden quadrangles)

B - RICEVILLE 15′ RADIOMETRIC MAP (Covers Mount Airy, Republican Grove and Java quadrangles)

C - DRAPER 15′ RADIOMETRIC MAP (Covers Whitmell, Draper, and Brosville quadrangles)

D - DANVILLE 15′ RADIOMETRIC MAP (Covers Mt. Hermon, Blairs, and Danville quadrangles)

CONTRIBUTIONS TO VIRGINIA GEOLOGY

The Division of Mineral Resources is currently accepting papers on Virginia geology from writers outside the Division for possible publication. Instructions on preparation of manuscripts and also review forms will be mailed upon written request. At least two reviews will need be procured by writers. Papers not accepted for publication may be placed on open file with the Division if writers wish to do so.

NEW CAVE PROTECTION ACT

In January 1978 members of the Virginia Region of the National Speleological Society, alarmed by the accelerating degradation of Virginia's cave resources, asked The Honorable Bill Axselle of Richmond to introduce legislation into the Virginia General Assembly which would create a commission to study the conservation of cave resources. The legislation (House Joint Resolution No. 10) was passed in amended form and an eleven member commission was appointed by Governor Dalton to "study all problems incidental to cave use, protection, and conservation in Virginia."

The Commission on the Conservation of Caves completed its study in December 1978 and submitted its findings to the Governor and General Assembly (House Document No. 5, 1978). The Commission's report documented the rapid deterioration of Virginia's caves as geologic, archeologic, biologic, recreational, and educational resources. Further, the Commission made the following three recommendations: that an inventory of archeologic resources in Virginia caves be made, that a permanent Cave commission be created, and that a new Cave protection Act giving broader protection to cave resources be enacted.

The 1979 session of the General Assembly, responding to the recommendations of the Commission on the Conservation of Caves, created the Virginia Cave Commission and enacted the new comprehensive Cave Protection Act.

The new Virginia Cave Protection Act has two basic objectives - to protect Virginia's cave resources from vandalism and degradation and to protect the cave owner's interest in his property. Most violations of the law are Class 3 misdemeanors, punishable by a fine of up to five hundred dollars.

Under the provisions of this new law it is illegal to remove, mar, or otherwise disturb any natural mineral formation or sedimentary deposit in any cave without the owner's express, prior, written permission. Although collection of mineral specimens is not completely prohibited, it was the intent of the Commission on the Conservation of Caves that future collection be as minimal, selective, and scientific as possible. This law is designed to preserve the beauty of Virginia's caves and prevent them from being destroyed by indiscriminate collection and by vandalism.

It is also illegal to sell or export for sale speleothems (mineral formations or deposits found in caves) under the new Virginia Cave Protection Act. By eliminating the market for speleothems, much of the incentive for speleothem theft is also eliminated.

Caves are unique natural laboratories for the investigation of biologic processes. Natural organisms found in caves live in fragile environments where even small disturbances by man can produce catastrophic changes in cave ecosystems. Many of the more than 200 animal species found in Virginia caves are restricted to small geographical areas and occur in very small populations. A number of Virginia's cave animals, including three species of bats, have been placed on the Federal Endangered Species List. The new Cave Protection Act prohibits disturbing or harming any cave organism. Permits for the collection of biologic specimens can be obtained from the Cave Commission.

The pollution of groundwater as a result of the dumping of garbage, sewage, dead farm animals, and toxic wastes into caves and sinkholes is a problem in the limestone areas of Virginia. Caves provide natural conduits for groundwater flow, which concentrate groundwater pollutants. This contamination not only adversely affects man, but also organisms within the cave system. Under the new Virginia Cave Protection Act it is illegal to dump any litter, waste material, or toxic substance in any cave without the express, prior, written permission of the owner.

Virginia caves contain important archeologic sites. There are 26 known Indian-burial caves and at least 50 saltpetre caves in the State. Such cave can contain a wealth of scientific data on the prehistoric and historic cultures which used them. Unfortunately, much of the information that these sites could yield to trained scientists, may have been lost as a result of disturbance by vandals and souvenir hunters. To protect the remaining archeologic resources found in Virginia caves, the new Cave Protection Act requires a permit to be obtained from the Virginia Historic Landmarks Commission and written permission from the cave owner before excavating, removing, or disturbing any fossils, historic artifacts, or prehistoric remains.

The Cave Protection Act also protects gates, locks, and other barriers designed by the cave owner to prevent or to control access to his cave. It is illegal to break, force, or tamper with these barriers or to remove or deface any sign posted by the owner. The cave owner is also exempted from liability for any injury sustained in his cave as long as he has not charged an admission fee.

Below is the complete text of the new Virginia Cave Protection Act. If you have any questions regarding caves, the act or its enforcement, please write to the Virginia Cave Commission, c/o BSC, P. O. Box 6532, Charlottesville, Virginia 22906.

Robert W. Custard

CHAPTER 12.2

10-150.11. Findings and policy - The General Assembly hereby finds that caves are uncommon geologic phenomena, and that the minerals deposited therein may be rare and occur in unique forms of great beauty which are irreplaceable if destroyed. Also irreplaceable are the archeological resources in caves which are of great scientific and historic value. It is further found that the organisms which live in caves are unusual and of limited numbers; that many are rare and endangered species; and that caves are a natural conduit for grounwater flow and are highly subject to water pollution, thus having far-reaching effects transcending man's property boundaries. It is therefore declared to be the policy of the General Assembly and the intent of this chapter to protect these unique natural and cultural resources.

10-150.12. Definitions. - As used in this chapter, the following words shall have the meanings stated unless the context requires otherwise:

A. "Cave" means any naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth or within a cliff or ledge including natural subsurface water and drainage systems, but not including any mine, tunnel, aqueduct, or other man-made excavation, which is large enough to permit a person to enter. The word "cave" includes or is synonymous with cavern, sinkhole, natural pit, grotto, and rock shelter.

B. "Commercial cave" means any cave utilized by the owner for the purposes of exhibition to the general public as a profit or nonprofit enterprise, wherein a fee is collected for entry.

C. "Gate" means any structure or device located to limit or prohibit access or entry to any cave.

D. "Sinkhole" means a closed topographic depression or basin, generally draining underground, including, but not restricted to, a doline, uvala, blind valley, or sink.

E. "Person" or "persons" means any individual, partnership, firm, association, trust, or corporation or other legal entity.

F. "Owner" means a person who owns title to land where a cave is located, including a person who owns title to a leasehold estate in such land, and specifically including the Commonwealth

and any of its agencies, departments, boards, bureaus, commissions, or authorities, as well as counties, municipalities, and other political subdivisions of the Commonwealth.

G. "Speleothem" means a natural mineral formation or deposit occurring in a cave. This includes or is synonymous with stalagmite, stalactite, helectite, shield, anthodite, gypsum flower and needle, angel's hair, soda straw, drapery, bacon, cave pearl, popcorn (coral), rimstone dam, column, palette, flowstone, et cetera. Speleothems are commonly composed of calcite, epsomite, gypsum, aragonite, celestite, and other similar minerals.

H. "Speleogen" means an erosional feature of the cave boundary and includes or is synonymous with anastomoses, scallops, rills, flutes, spongework, and pendants.

I. "Material" means all or any part of any archeological, paleontological, biological, or historical item including, but not limited to, any petroglyph, pictograph, basketry, human remains, tool, beads, pottery, projectile point, remains of historical mining activity or any other occupation, found in any cave.

J. "Cave life" means any life form which normally occurs in uses, visits, or inhabits any cave or subterranean water system, excepting those animals and species covered by any of the game laws of the Commonwealth.

10-150.13. Vandalism; penalties. - A. It shall be unlawful for any person, without express, prior, written permission of the owner, to:

1. Break, break off, crack, carve upon, write, burn, or otherwise mark upon, remove, or in any manner destroy, disturb, deface, mar, or harm the surfaces of any cave or any natural material which may be found therein, whether attached or broken, including speleothems, speleogens, and sedimentary deposits. The provisions of this section shall not prohibit minimal disturbance for sceintific exploration.

2. Break, force, tamper with, or otherwise disturb a lock, gate, door, or other obstruction designed to control or prevent access to any cave, even though entrance thereto may not be gained.

3. Remove, deface, or tamper with a sign stating that a cave is posted or citing provisions of this chapter.

B. The entering or remaining in a cave which has not been posted by the owner shall not by itself constitute a violation of this section.

C. Any violation of this section shall be punished as a Class 3 misdemeanor.

10-150.14 Pollution unlawful; penalties. - A. It shall be unlawful for any person without express, prior written permission of the owner to store, dump, litter, dispose of or otherwise place any refuse, garbage, dead animals, sewage, toxic substances harmful to cave life or humans in any cave or sinkhole. It shall also be unlawful to burn within a cave or sinkhole any material which produces any smoke or gas which is harmful to any naturally occurring organism in any cave.

B. Any violation of this section shall be punished as a Class 3 misdemeanor.

10-150.15. Biological policy; penalties for violation. - A. It shall be unlawful to remove, kill, harm, or otherwise disturb any naturally occuring organisms within any cave, except for safety or health reasons; provided, however, scientific collecting permits may be obtained from any cave commission established for such purpose or form the appropriate State agency.

B. Any violation of this section shall be punished as a Class 3 misdemeanor.

10-150.16. Archeology; permits for excavation; how obtained; penalties for violation. - A. In order to protect the archeological resources not covered by the Virginia Antiquities Act (10-150.1 et seq.), it shall be unlawful to excavate, remove, destroy, injure, deface, or in any manner disturb any burial grounds, historic or prehistoric resources, archeological or paleontological site or any part thereof, including relics, inscriptions, saltpetre workings, fossils, bones, remains of historical human activity, or any other such features which may be found in any cave, except those caves owned by the Commonwealth or designated as Commonwealth archeological sites or zones, and which are subject to the provisions of the Virginia Antiquities Act. Any violation of this subsection shall be punished as a Class 3 misdemeanor.

B. Notwithstanding the provisions of subsection A. hereof, a permit to excavate or remove archeological, paleontological prehistoric, and historic features may be obtained from the Virginia Historic Landmarks Commission. The Commission may issue a permit to conduct field investigations if the Commission finds that it is in the best interest of the Commonwealth, that the applicant meets the criteria of this section and the applicant is an historic, scientific, or educational institution, professional archeologist or amateur, who is qualified and recognized in the areas of field investigations or archeology. Such permit shall be issued for a period of two years and may be renewed upon expiration. Such permit shall not be transferrable; provided, however, the provisions of this section shall not preclude any person from working under the direct supervision of the permittee.

C. All field investigations, explorations, or recovery operations undertaken under this section shall be carried out under the general supervision of the Commissioner of Archeology of the Virginia Research Center for Archeology and the Virginia Historic Landmarks Commission and in a manner to insure that the maximum amount of historic, scientific, archeologic, and educational information may be recovered and preserved in addition to the physical recovery of objects.

D. A person applying for a permit pursuant to this section shall:

1. Have knowledge of archeology or history as qualified in subsection b. hereof.

2. Provide a detailed statement to the Commission giving the reasons and objectives for excavation or removal and the benefits expected to be obtained from the contemplated work.

3. Provide data and results of any completed excavation, study, or collection at the first of each calendar year.

4. Obtain the prior written permission of the owner if the site of the proposed excavation is on privately owned land.

5. Carry the permit while exercising the privileges granted.

E. Any violation of subsection A. hereof shall be punished as a Class 3 misdemeanor. Any violation of subsection D. hereof shall be punished as a Class 4 misdemeanor, and the permit shall be revoked.

F. The provisions of this section shall not apply to any person in any cave located on his own property.

10-150.17. Sale of speleothems unlawful; penalties. - It shall be unlawful for any person to sell or offer for sale any speleothems in this Commonwealth, or to export them for sale outside the Commonwealth. Any violation of this section shall be punished as a Class 3 misdemeanor.

10-150.18. Liability of owners and agents limited. - A. Neither the owner of a cave or his authorized agents acting within the scope of their authority are liable for injuries sustained by any person using the cave for recreational or scientific purposes if no charge has been made for the use of the cave, notwithstanding that an inquiry as to the experience or expertise of the individual seeking consent may have been made.

Nothing in this section shall be construed to constitute a wavier of the sovereign immunity of the Commonwealth or any of its boards, departments, bureaus, or agencies.

2. That 18.2-142 of the Code of Virginia is repealed.

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VIRGINIA MINERALS AVAILABLE

Beginning January 1980, extra issues of **Virginia Minerals** will be available at a cost of $0.52 each (includes four precent State sales tax). Reproducible machine copies will be provided for any issue which has been depleted. An index to the issues is available free upon request from the Division.

COAL RESERVE REVISION

The Virginia Division of Mineral Resources has begun a program of revising the coal reserve estimates for the Southwest Virginia Coal Field in cooperation with the U. S. Geological Survey. Results of this study will be useful to all levels of government, mining companies and mining equipment and service suppliers in anticipating future coal development in Virginia. The last estimate of coal reserves was made by the U. S. Geological Survey and was published in 1952.

As a first step in gathering data for the reserve estimate, Division geologists are visting all working coal mines in the State. At each mine, geological data on coal thickness, quality and development potential will be collected. Division personnel will also measure and describe available coal exposures in road cuts and streams. The Division's published report will consist of calculated reserve tables compiled by county and coal bed. Data reported will not disclose the amount of coal present or previously mined on individual properties. The Division of Mineral Resources has enjoyed good working relationship with Virginia's coal operators and anticipates continued invaluable company cooperation in this project.

APPALACHIAN SULFIDE DEPOSIT MAP AVAILABLE

The Division of Mineral Resources has received an open file copy of a black and white version of "Lithostratigraphic, Structural Setting of Stratabound (Massive) sulfide Deposits, U. S. Appalachians," by Jacob E. Gair and John F. Slack, U. S. Geological Open File Report 79-1517. The report consists of two map sheets on a scale of 1:1,000,000 showing 103 ~~sulfide deposits from Alabama to Maine~~; 13 of these are in Virginia. The deposits are grouped by size and by base metal and iron sulfide content. Two additional sheets in the report give the following details in tabular form: tectonic unit or postion; age of host rock; general host rock lithology; metamorphic grade; shape; size; mode of aggregation; dominant iron-sulfide; grade for S, Cu, Zn, Pb, Au, Ag; other elements of special interest; comments on history and geology; and references. The deposits are plotted on a generalized geologic map depicting regionally correlated lithologies and plutons of similar age with explanatory legend.

The report is a product of the International Geological Correlation Programme (IGCP) Project No. 60 on the correlation of Caledonian stratabound sulfides. The maps and tables correspond to similar maps and tables for the Caledonian orogen for Canada, Greenland, Ireland, Scotland, Norway, and Sweden being produced by national groups involved in the international project.

These maps may be seen in the Division's library or purchased from:

Open File Services
Branch of Distribution
Box 25425
Federal Center
Denver, Colorado 80225

Phone: 303-234-5888

VIRGINIA MINERALS

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
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ROAD LOG TO THE GEOLOGY OF THE ABINGDON AND SHADY VALLEY QUADRANGLES

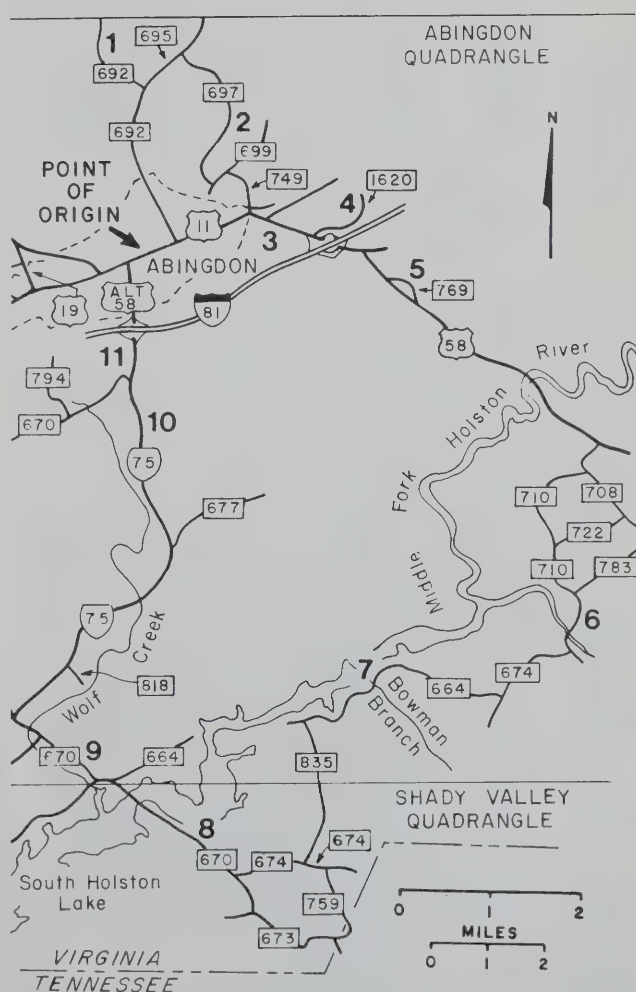
Charles Bartlett and Thomas Biggs

This road log is a guide to some of the significant geologic features in the Abingdon and Shady Valley quadrangles. The lower Paleozoic rocks in this area are mainly carbonates and shales. At places fossil gastropods are in the carbonates and there are graptolites in the Athens shales. The strata lie in a sequence of major folds, both open and overturned, characteristic of the Ridge and Valley province. The route crosses these structures and also the Pulaski, Spurgeon and Alvarado thrust faults and the Dry Run cross fault. Cataclastic rocks are associated with the faults. Karst topography is well developed in the Holston River Valley.

A generalized map of the area showing the 41-mile route of the road log is shown. Topographic maps of the Abingdon and Shady Valley quadrangles may be obtained from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903. A county road map of Washington County is available from the Information Office, Virginia Department of Highways, 1221 East Broad Street, Richmond, Virginia 23219 or the Residency Shop in Ablingdon.

Permission should always be obtained before entering private property.

CUMULATIVE DISTANCE MILES Km	*DISTANCE* MILES Km	*EXPLANATION*
0.0	**0.0**	Begin in Abingdon at the fire hydrant on Main Street (U. S. Highway 11) in front of the Martha Washington Inn. Head east.
0.0	0.0	
0.4	**0.4**	Washington County Courthouse on left.
0.64	0.64	
0.5	**0.1**	House on left. Behind house is "Wolf Cave" formed in Chepultepec limestone. It is said that wolves from this cave attacked a party led by Daniel Boone, hence an early name for Abingdon was Wolf Hills.
0.80	0.16	



Index map for road log.

CUMULATIVE DISTANCE MILES Km	DISTANCE MILES Km	EXPLANATION
0.6 0.97	**0.1** 0.16	Turn left onto Tanner Street.
0.7 1.13	**0.1** 0.16	Turn right onto Valley Street.
0.8 1.29	**0.1** 0.16	Turn left onto State Road 692 (White Mill Road).
2.0 3.22	**1.2** 1.93	Sandstone from the Conococheague Formation in the right roadbank.
2.1 3.38	**0.1** 0.16	Shale chips weathered from the Nolichucky in the right roadbank.
2.4 3.86	**0.3** 0.48	Conococheague and Nolichucky beds are overridden by the Honaker dolomite along small thrust fault.
2.6 4.19	**0.2** 0.32	Road junction with State Road 695, bear left and continue on State Road 692.
2.9 4.67	**0.3** 0.48	In left roadcut is Honaker dolomite which has south dip.
3.3 5.30	**0.4** 0.64	In right roadbank is fractured Honaker dolomite.
3.5 5.62	**0.2** 0.32	**STOP 1.** Honaker dolomite with abundant fractures and calcite veins on right in roadcut. Zone is near the base of a secondary thrust sheet associated with the Pulaski fault. Continue north.
3.9 6.28	**0.4** 0.64	The small valley on the right lies on the trace of the main Pulaski thrust fault along which the Honaker Formation is in contact with the Knox Group, upper part.
4.0 6.44	**0.1** 0.16	Outcrops in right road bank are dolomite with white chert of the Knox Group, upper part.
4.3 6.92	**0.3** 0.48	Return south to State Road 695.
6.0 9.66	**1.7** 2.74	Turn left onto State Road 695.
6.5 10.46	**0.5** 0.80	Some deep sinkholes on the left in a limestone and dolomite unit in the middle portion of the Honaker Formation.
6.7 9.79	**0.2** 0.32	Turn right onto State Route 697.
6.9 11.11	**0.2** 0.32	Outcrops on left: dolomite in upper part of Honaker Formation.
7.2 11.59	**0.3** 0.48	Weathered Nolichucky shale in left roadbank.
7.3 11.75	**0.1** 0.16	Sandstone layers near base of Conococheague Formation in left roadbank.
7.5 12.07	**0.2** 0.32	On left limestone and dolomite of Conococheague Formation. Note springs near the creek.
8.1 13.04	**0.6** 0.97	**STOP 2.** Conococheague Formation outcrops are on left of road. Rocks of this unit include light-gray dolomite, laminated bluish-gray limestone and a layer of limestone-pebble conglomerate.
8.6 13.84	**0.5** 0.80	Abandoned quarry on left at curve is in Conococheague Formation dolomite and limestone.
8.8 14.16	**0.2** 0.32	Turn left onto State Road 699.
9.0 14.48	**0.2** 0.32	Turn right onto road to E. B. Stanley Elementary School.
9.2 14.80	**0.2** 0.32	Outcrops of Conococheague sandstone and limestone on right in front of school.
9.5 15.28	**0.3** 0.48	On right behind the William Neff Technical School (circular building) is thick-bedded Chepultepec limestone.
9.7 15.62	**0.2** 0.32	Turn left onto State Road 749 at County school office building.
9.9 15.94	**0.2** 0.32	Stop sign. Turn left on U. S. Highway 11.
10.0 16.10	**0.1** 0.16	Cross Norfolk and Western Railway overpass.
10.4 16.74	**0.4** 0.64	**STOP 3.** Spurgeon fault trace with bouldery breccia exposed on both sides of the highway. Breccia is in near vertical beds of the Honaker Formation which was thrust upon the Knox Group, upper part. The fault overlies a portion of the axial trace of the Abingdon syncline. Continue to southeast on U. S. Highway 11.
10.8 17.38	**0.4** 0.64	Turn left at Texaco station onto service road on north side of Interstate Highway 81.
11.4 18.34	**0.6** 0.97	Turn left onto State Road 1620.
11.45 18.43	**0.05** 0.08	**STOP 4.** Walk 50 yards west to small waterfalls in Fifteenmile Creek; waterfalls are formed in Nolichucky limestone beds. Beds here are representative of this unit in areas south of the Spurgeon fault. The reddish-brown, wavy, silty, raised laminae in the bluish-gray micrite is distinctive. Note also thin lenses of oolitic, fossiliferous limestone-pebble conglomerate. The site of an ancient Indian campground was partially excavated here in 1972. A charcoal sample from the site dated 585 A.D. Continue north into a housing development.
11.7 18.84	**0.25** 0.40	Turn around. The Spurgeon fault may be traced on the hill to the west (across the creek). Nearly vertical beds of Honaker Formation and more gently inclined beds of Chepultepec limestone are north of the fault. The strike of the Honaker beds is almost perpendicular to that of the Chepultepec. Return to U. S. Highway 11.
12.6 20.29	**0.9** 1.45	Stop sign. Turn left onto U. S. Highway 11.
12.7 20.45	**0.1** 0.16	Pass under Interstate Highway 81.
13.1 21.09	**0.4** 0.64	Turn right onto U. S. Highway 58 (J. E. B. Stuart Highway).
13.4 21.57	**0.3** 0.48	Overturned and cleaved, graptolite-bearing Athens shales in right roadcut.
13.7 22.06	**0.3** 0.48	Turn left onto State Road 769, a gravel road.

CUMULATIVE DISTANCE **MILES** Km	*DISTANCE* **MILES** Km	*EXPLANATION*
14.0 22.54	**0.3** 0.48	**STOP 5.** Large borrow pit in Athens Formation shale which contains beds with thin siltstone partings and axial plane cleavage. Dip is about 35 degrees to the northwest into the Great Knobs syncline. Continue south.
14.1 22.70	**0.1** 0.16	Quarry on left in limestones of Lenoir-Mosheim and dolomite of Knox Group, upper part. Stop sign; turn left onto U. S. Highway 58.
14.6 23.50	**0.5** 0.80	Road is at angle of dip slope of Conococheague beds.
14.9 23.98	**0.3** 0.48	Crest of hill is at axis of Watauga anticline.
15.4 24.78	**0.5** 0.80	Roadbank exposures of south dipping dolomite in Knox Group, upper part.
15.7 25.26	**0.3** 0.48	Hillside cuts in Athens Formation.
15.8 25.58	**0.1** 0.16	Bridge over Middle Fork Holston River.
15.9 25.53	**0.1** 0.16	Rapids on right in river formed by resistive sandstone and siltstone layers in Athens Formation near axis of River Knobs syncline.
16.3 26.24	**0.4** 0.64	Road cut through dark-gray, fissle shale of Athens Formation with thin layers of sooty-gray bentonite (?) and with pyrite and tiny gypsum crystals.
16.7 26.88	**0.4** 0.64	Roadway on dip slope of dolomite in Knox Group, upper part, on north flank of Parks Mill anticline.
17.0 27.36	**0.3** 0.48	Crossing axial trace of Park Mill anticline.
17.1 27.52	**0.1** 0.16	Turn right onto State Road 708.
17.4 28.00	**0.3** 0.48	Sharp left curve.
17.5 28.16	**0.1** 0.16	Road junction at right with State Road 710, continue on 708.
17.7 28.48	**0.2** 0.32	Bethel Elementary School on left.
18.0 29.96	**0.3** 0.48	Outcrops in fields of Lenoir-Mosheim limestone with some conglomerate at the base of the unit (Middle Ordovician unconformity). To left, on hillslope, is exposure of shale in the Athens Formation which is in a syncline.
18.1 29.12	**0.1** 0.16	Crossing axial trace of same syncline. Holston Mountain is on horizon ahead.
18.2 29.30	**0.1** 0.16	Turn right onto State Road 722.
18.7 30.10	**0.5** 0.80	Karst topography on left in Chepultepec limestone; solution weathering is enhanced by fractures along a thrust fault. Note the disappearing stream in pig pen.
19.1 30.74	**0.4** 0.64	To the right along creek are outcrops of Chepultepec limestone.
19.2 30.90	**0.1** 0.16	Junction on right with State Road 710; continue ahead on State Road 710.
19.3 31.06	**0.1** 0.16	Trace of an unnamed thrust fault intersects road.
19.5 31.38	**0.2** 0.32	Outcrops in left roadbank of limestone in Conococheague Formation.
19.8 31.86	**0.3** 0.48	Roadcut on left in Conococheague limestone with two prominent sandstone beds. Just beyond is junction with State Road 783; turn right and continue on State Road 710.
20.3 32.66	**0.5** 0.80	**STOP 6.** Roadcut in limestone and dolomite assigned to the Chepultepec and Knox Group, upper part. Note terrace gravels high on outcrop at left. Walk ahead 50 yards to bridge on South Fork Holston River. Upstream are rapids of resistive Lenoir-Mosheim limestone. The trace of the Alvarado cross fault is beneath the west end of the bridge.
20.35 32.76	**0.05** 0.08	Cross bridge. Hill on right ahead is of Athens Formation.
20.5 33.00	**0.15** 0.24	Alvarado community.
20.55 33.08	**0.05** 0.08	Cross Norfolk and Western Railway tracks.
20.7 33.32	**0.15** 0.24	Turn right onto State Road 674.
20.8 33.48	**0.1** 0.16	Outcrops near road are Knox Group, upper part.
21.2 34.12	**0.4** 0.64	About 100 feet at right, Lenoir-Mosheim limestones terminate against Athens shale at a normal fault. Beyond, about 150 yards north of the road, is an exposure of southward dipping, Middle Ordovician rocks in a fault-bounded, graben-like structure.
21.55 34.68	**0.35** 0.56	Base of Athens Formation.
22.0 35.40	**0.45** 0.72	Turn right onto gravel road, State Road 664, to South Holston Lake.
22.05 35.48	**0.05** 0.08	On left are overturned beds of Lenoir-Mosheim limestones.
22.1 35.58	**0.05** 0.08	Roadcut on left in overturned Athens shale.
22.35 35.98	**0.25** 0.40	Outcrops on both sides of road are in Knox Group, upper part dolomite and Lenoir-Mosheim limestone. The dip is south.
22.4 36.06	**0.05** 0.08	Right roadcut has vertical beds of Athens shale.
22.45 36.14	**0.05** 0.08	Thick-bedded conglomeratic sandstones on right have steep dip to the northwest.
22.6 36.38	**0.15** 0.24	The same conglomeratic sandstone unit has dip to southeast. The principal axis of the South Holston syncline lies between these two exposures.
23.3 37.51	**0.7** 1.13	Lenoir-Mosheim limestone on left roadbank and on hillslope to right across Bumgardner Branch.
23.9 38.47	**0.6** 0.96	**STOP 7.** From top of hill walk 50 yards to right (west) toward Bowman Branch. Trench in hemlock grove is an old iron prospect pit in cherty dolomite of the Knox Group, upper part. These trenches, which are both sides of Bowman Branch, represent the Riverside, or Holston,

CUMULATIVE DISTANCE **MILES** Km	*DISTANCE* **MILES** Km	*EXPLANATION*
		mine.
24.0 38.64	**0.1** 0.16	Outcrops here and for the next 3.5 miles (5.6 km) are primarily in Athens Formation shales and sandstones which are steeply inclined southward and are partly overturned.
24.2 38.96	**0.2** 0.32	Iron prospect pits in woods on right.
24.7 39.76	**0.5** 0.80	Outcrop of Lenoir-Mosheim limestone in Mays Branch.
25.6 41.21	**0.9** 1.45	Road junction, turn left onto State Road 835.
26.3 42.34	**0.7** 1.13	On left are some ledges of conglomeratic sandstone in the Athens.
26.4 42.50	**0.1** 0.16	Additional ledges of conglomeratic sandstone.
26.8 43.14	**0.4** 0.64	Cross Lick Branch. Just across creek is folded and contorted Athens shale and siltstone.
27.0 43.46	**0.2** 0.32	Additional folded Athens beds on right bank.
27.5 44.28	**0.5** 0.80	Road junction, turn left onto State Road 674. In flat field just ahead is approximate trace of Dry Branch cross fault; hill is underlain by Chepultepec limestone which is mostly overturned; dip is to the southeast.
27.85 44.84	**0.35** 0.56	Turn right onto State Road 759.
27.9 44.92	**0.05** 0.08	On left bank are sandstone gravels of a former steam channel in Athens shale. Ahead is Holston Mountain.
27.95 45.00	**0.05** 0.08	Cross trace of Dry Creek fault.
28.0 45.08	**0.05** 0.08	On right hillslope are Conococheague Formation outcrops; dip is about 64 degrees northwest.
28.6 46.05	**0.6** 0.97	Enter Sullivan County, Tennessee.
28.9 46.53	**0.3** 0.48	Re-enter Washington County, Virginia Ditches on both sides contain weathered maroon shales of the Rome Formation.
29.1 46.85	**0.2** 0.32	Road junction, turn right onto State Road 673. Hillslope on right are of highly contorted dolomite of Honaker Formation.
29.7 47.82	**0.6** 0.97	Sandstone and quartzite colluvial gravels on left bank.
29.9 48.14	**0.2** 0.32	Good exposure in field to right of overturned Honaker dolomite and limestone.
30.1 48.46	**0.2** 0.32	On left in curve of road just northwest of a driveway is laminated limestone of the Nolichucky Formation. The lithology is nearly identical to that near Abingdon (see Stop 4).
30.2 48.62	**0.1** 0.16	On clear days Clinch Mountain can be seen in the distance straight ahead.
30.45 49.02	**0.25** 0.40	Turn right onto State Road 670.
30.5 49.10	**0.05** 0.08	Outcrops on right in overturned Conococheague limestone, dolomite and sandstone.
30.7 49.42	**0.2** 0.32	Overturned beds of Chepultepec limestone on right.
30.9 49.74	**0.2** 0.32	At barn on left is dolomite of the Knox Group, upper part, and limestone of Lenoir-Mosheim, which contains some dolomite-pebble conglomerate at its base. The beds are overturned; dip is southeast.
30.95 49.82	**0.05** 0.08	Graptolite-bearing shales near base of Athens Formation in left roadcut.
31.05 49.96	**0.1** 0.16	Road junction with State Road 674. At stop sign turn left onto 670.
31.5 50.72	**0.45** 0.72	Bedding plane surface of Athens exposed on right has mudcracks.
31.7 51.04	**0.2** 0.32	**STOP 8.** Trace of Dry Run cross fault is along lake. Across road is a spectacular example of polymictic conglomerate of the Athens Formation. Pebbles of limestone, dolomite, chert, jasper, and quartzite are in several layers. Continue north.
31.9 51.36	**0.2** 0.32	South Holston Lake to right.
32.6 52.49	**0.7** 1.13	Avens Bridge over South Holston Lake. Athens Formation shales and siltstones are to the left and Knox Group, upper part and Lenoir-Mosheim beds are to the right. Good exposures of Middle Ordovician unconformity and associated erosional conglomerates are on north shore to right.
33.0 53.13	**0.4** 0.64	Road junction with State Road 664; continue ahead on State Road 670.
33.2 53.45	**0.2** 0.32	**STOP 9.** Park on left of road. To right, roadcut is in Conococheague Formation; rocks include cross-bedded and ripple-marked sandstone, thin laminated dolomite, limestone with algal-mound structures, ribbon-banded limestone and some chert nodules. Continue north.
33.5 53.94	**0.3** 0.48	Cross axis of Parks Mill anticline. Fold axis is in Conococheague beds on the hillslope on the left across Wolf Creek.
33.9 54.58	**0.4** 0.64	Stop sign. Junction with State Highway 75. Continue ahead to northwest on State Highway 75. Outcrops on left are Chepultepec limestone.
34.15 54.98	**0.25** 0.40	Bridge over Wolf Creek. Outcrops on left ahead are Lenoir-Mosheim limestones; dip is northwest.
34.3 55.22	**0.15** 0.24	On right bank of creek graptolite-bearing, fissile Athens shale lies near axis of River Knobs syncline.
34.45 55.48	**0.15** 0.24	Sharp right turn on State Highway 75 at junction with State Road 665. Continue on State Road 75.
35.0 56.35	**0.55** 0.88	Sinkholes and karst topography on left in Chepultepec limestone along axis of Watauga anticline. Gastropod-rich limestone beds of the Knox Group, upper part, and Lenoir-Mosheim are on the lower slopes of hill on right.
35.8 57.63	**0.8** 1.28	Rock walls of house on left are of chert weathered from the Knox Group, upper part.
36.7	**0.9**	Bridge across Wolf Creek. Outcrops in

CUMULATIVE DISTANCE MILES Km	*DISTANCE* MILES Km	*EXPLANATION*
59.08	1.45	creek of Knox Group, upper part dolomite at the axis of the Watauga anticline.
37.5 60.37	0.8 1.29	Road junction on right with State Road 677, turn left and continue north on State Highway 75.
37.9 61.02	0.4 0.64	Dip of Athens shale in quarry on right is 43 degrees northwest into the Great Knobs syncline.
38.1 61.34	0.2 0.32	Conglomeratic arkosic sandstones of the Athens Formation exposed in right roadcut.
38.4 61.82	0.3 0.48	Small synclinal fold in Athens sandstones on right.
38.5 61.98	0.1 0.16	**STOP 10.** Fault in Athens Formation sandstone and shale in roadcut on right at a curve in the road.
38.85 62.54	0.35 0.56	Beds of Athens Formation in roadcut on left are folded and fractured. Formation is prone to rapid mass wasting on steep slope such as in cut.
39.4 63.42	0.55 0.88	On the right are nearly vertical beds of Athens Formation on the north side of Great Knobs syncline.
39.6 63.74	0.2 0.32	Road construction in 1972 sliced through an ancient, pallisaded Indian village which dates at 1425 A.D.
39.9 64.22	0.3 0.48	**STOP 11.** Alvarado fault zone is exposed in roadcut and in a small pit on left side of road. Beds of limestone and dolomite in the Conococheague are highly contorted where the trend of the fault changes from northwest to east - southeast.
40.3 64.88	0.4 0.64	Interstate Highway 81 underpass. Axis of Stone Mill anticline.
40.85 65.76	0.55 0.88	Crossing axial trace of Abingdon syncline.
40.95 65.92	0.1 0.16	Crossing trace of Spurgeon thrust fault.
41.0 66.00	0.05 0.08	Norfolk and Western Railway overpass. To left along railroad are outcrops of the Knox Group, upper part dolomite which is in fault contact with Conococheague rocks.

END OF ROAD LOG

STAFF NOTES

Effective Dec. 1, 1979 Dr. Mervin J. Bartholomew, a native of Pennsylvania, joined the permanent staff of the Division of Mineral Resources where he had worked as a nonpermanent employee for the previous 2½ years in the western mapping section. Jerry received his B.S. in geological sciences from The Pennsylvania State University in 1964. This was followed by a year of graduate work at the University of Georgia before moving to California in 1965. There he accepted a job with Standard Oil Company of California (Chevron) for whom he worked until 1968. During the 3 years he worked at their Inglewood district office he attended night school at the University of Southern California where he received his M.S. in geology in 1969. During these years he also gained additional field experience with Tennessee Copper Company and the Central Savannah River Area Project in Alabama and Georgia, respectively, as well as with the Atlantic-Richfield Oil Company and the Los Angeles County Museum in California.

In 1971 Jerry received his Ph.D. in geological sciences from the Virginia Polytechnic Institute & State University and subsequently taught there as well as at North Carolina State University and Longwood College until 1975. Since 1975 he has done geologic mapping for both the Virginia Division of Mineral Resources and the North Carolina Division of Land Resources. In addition to publications prepared for both states, Jerry has also published articles on: the San Jacinto fault in California; late Quaternary faulting in The Olympic Peninsula in Washington; ptygmatic features; and the middle Ordovician Trilobite, **Microparia**.

Jerry currently works at the Department of Geological Sciences, Virginia Polytechnic Institute & State University where he serves on thesis committees of students whose research is funded by the Division. His current assignments include 7½-minute quadrangle mapping in the Roanoke-Pulaski-Pearisburg region as well as an examination of Mississippian coals in the same area.

WHAT'S IN A NAME?

Did you know that the mineral name amethyst was derived from the Greek words meaning "not" and "drunk" because the mineral was supposed to have the power to remedy drunkenness? "Garnet" came from the Latin word for pomegranate, whose seeds were thought to resemble the mineral.

The derivations of mineral names are diverse. Most are taken from personal names but many are based on mineral characteristics, geographical names, objects the mineral resembles and sometimes, on physical concepts.

In "Mineral Names: What Do They Mean?" published in 1979, Richard Scott Mitchell of the University of Virginia discusses various ways minerals have been named in the past and presents guidelines for naming newly discovered minerals. He also lists in alphabetical order 2600 mineral names and their origins. The book is available for $13.95 from Van Nostrand Reinhold Company, 7625 Empire Drive, Florence, Kentucky 41042.

Purchase Instructions

GQ, I, P*, RI* and VB*	Order by letter and number designation from the following address. Most of these maps have accompanying explanatory reports. A List of Publications is available upon request. Virginia Division of Mineral Resources P. O. Box 3667 Charlottesville, Virginia 22903
B, GQ, I, MF, and WSP	Order by letter and number designation from: Branch of Distribution U.S. Geological Survey 1200 S. Eads Street Arlington, VA. 22202
OF	Order by letter and number designation from: Open-File Services U.S. Geological Survey Federal Center Box 25425 Denver, Colorado 80225

B — Bulletins, GQ — Geologic Quadrangles, I — Miscellaneous Investigations Series, MF — Miscellaneous Field Studies, OF — Open File Reports, P — Publications, RI — Reports of Investigation, VB — Bulletins, WSP — Water Supply Papers

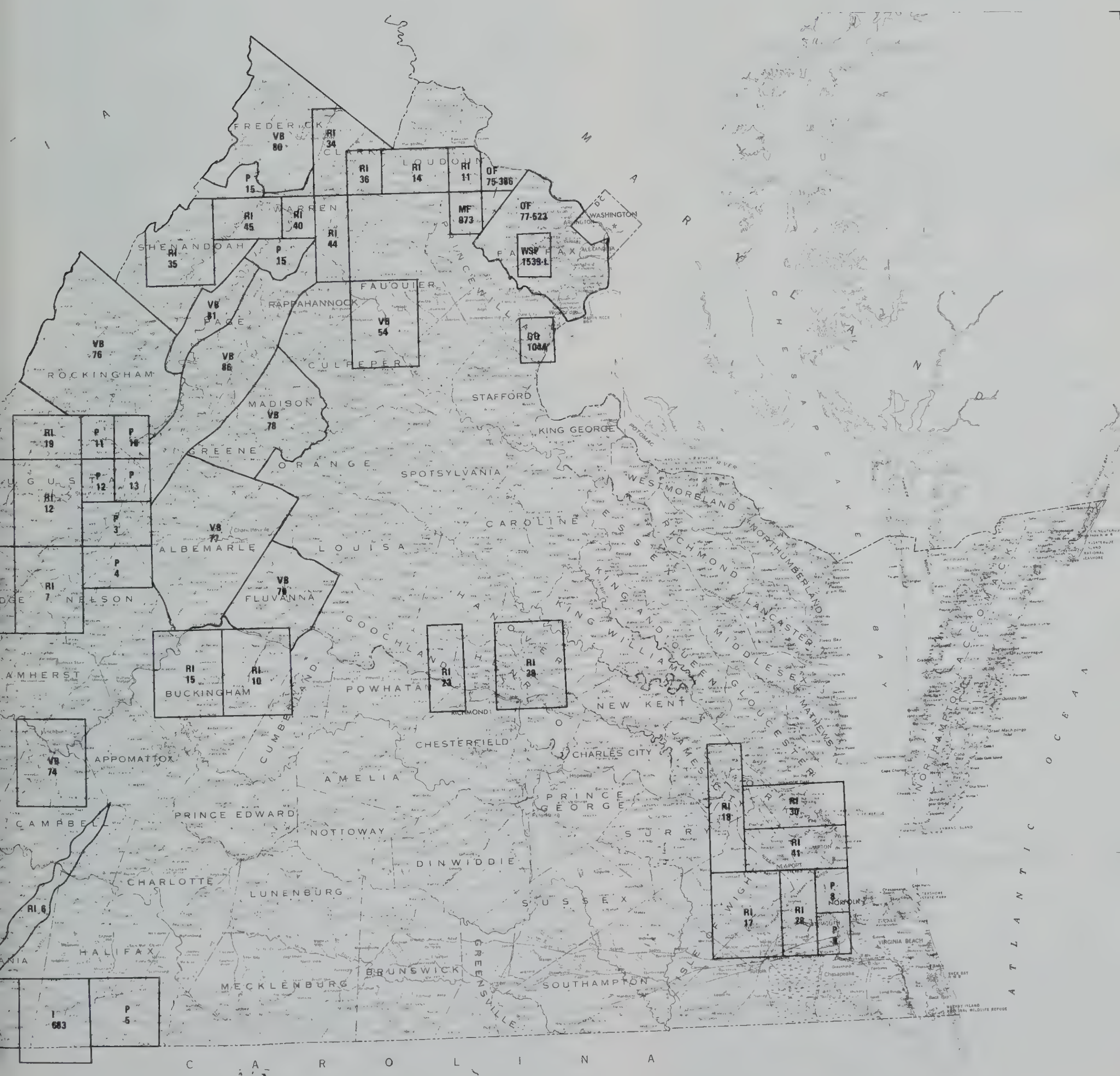
A listing of available, geologic publications by the Division on Virginia can be obtained from the above Charlottesville address.

*Published by Virginia Division of Mineral Resources, others by U.S. Geological Survey.

INDEX TO AVAILABLE GEOLOGIC MAPPING OF VIRGINIA

Scales 1:24,000 to 1:62,500

Mapped areas are outlined and labeled for reference in purchasing. Where several maps depict the same area only the more detailed map is shown.



AIME ABSTRACTS

The following are abstracts or portions of abstracts from papers which were presented at the November, 1979 meeting, of the Virginia Section of the American Institute of Mining Engineers held in Charlottesville. The theme of the meeting was "Mining and the Environment in Virginia". For more information on upcoming AIME meeings contact Richard S. Good or Robert C. Milici, Division of Mineral Resources, Box 3667, Charlottesville, Virginia 22903.

MATERIALS, ENERGY AND THE ENVIRONMENT: CONSTRAINTS AND INCENTIVES — CRISIS OR COMPROMISE

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The growth of the US economy and the American standard of living have resulted from the availability of material and energy resources and the financial and manufacturing capability to produce goods and services. The production of fuels and materials requires the disturbance of the environment, thereby leading to political, social and economic conflict relative to the trade-offs between materials, energy and the environment. Present laws involve constraints and incentives which are leading to a situation where the US is unable to produce domestically the materials and energy needed to sustain the economy and the standard of living while complying with environmental standards. This situation requires extensive imports of fuels and materials which lead to serious negative balance of fiscal payments. The resulting devaluation of the US dollar relative to foreign currency has led to serious inflation and escalating costs of the standard of living. Additionally US mining companies are leaving the US and seeking operations in nearby countries with less expensive resources and different environmental laws particularly oil, coke, aluminum, zinc, lead, alloys for steel and copper. Technical fixes to alleviate the situation require 10-12 year lead times. Thus, the near term forecasts suggest improved environment but very expensive materials and energy and thereby expensive goods and services with shortages unavoidable.

THE ACID MINE DRAINAGE OF CONTRARY CREEK: FACTORS CAUSING VARIATIONS IN STREAM WATER CHEMISTRY

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Contrary Creek in Louisa County, Virginia drains seven square miles of the piedmont's gold-pyrite belt. Three abandoned mines, the Sulfur, Boyd Smith and Arminius, are located within this small watershed. The oxidation of pyrite, chalcopyrite, sphalerite, and other sulfide minerals within the tailings and waste rock dumps of these mines releases sulfuric acid, iron, copper, zinc and other heavy metals into the groundwater. This acid and metal laden water seeps into Contrary Creek and maintains a base flow pollution load throughout the year. Several factors promote a wide variation in the chemical composition of the creek.

The distribution of mines along the length of the creek results in a pattern of increasing metal concentrations, metal loads and decreasing pH in the downstream direction. Tributaries which flow through mine dumps before confluence with Contrary Creek exhibit a similar longitudinal variation. Specific conductance and pH transects along the length of the creek and tributaries have been employed to locate sites of acid seepage from the mine dumps.

Seasonal fluctuations in the water table produce cyclical variations in the stream chemistry. Winter discharges, pH, and metal loads are high relative to those of the summer and conversely winter metal concentrations are consistently lower than those of the summer.

A ten percent diurnal variation of metal concentrations and discharge has been found in summer. The metal concentrations reach a maximum when the discharge and pH reach a minimum and vice versa. The metal loads, however, appear to remain unchanged. The diurnal nature of this phenomenon suggests a cause such as evaporation and/or transpiration which has a twenty-four hour periodicity to its intensity.

In addition to the temporal and longitudinal chemical variation found when the creek is approaching base flow, very rapid changes of the creek's chemistry follow the onset of a rainstorm. The concentrations of copper, zinc, iron, manganese, cadmium, and other metals increase very sharply during

the first few hours of rising discharge. Simultaneously metal loads rapidly increase and pH drops. The swift chemical response indicates that surface runoff transports the metals into the stream rather than water which has infiltrated and leached the tailings piles. Soluble efflorescent sulfate minerals such as melanterite, rozenite, ferricopiapite, halotrichite and chalcanthite are abundant during dry weather especially at the Sulfur Mine and they are inferred to be a major metal source for the surface runoff. Many other sulfates have been identified in lesser amounts i.e. alunogen, magnesiocopiapite, aluminocopiapite, pickeringite, gypsum, ferrohexahydrite, siderotil, szomolnokite, jarosite, rhomboclase, fibroferrite, coquimbite, paracoquimbite, antlerite, brochantite, linarite, anglesite, serpierite, gunningite, and epsomite. After the sulface efflorescences and crusts are flushed away, the unpolluted runoff from the upper watershed arrives. This relatively fresh water produces a net dilution of the creek.

GEOCHEMISTRY OF DUMPS AND DRAINAGE AT GOSSAN LEAD MINE, GALAX, VIRGINIA

Richard S. Good
Virginia Division of Mineral Resources

From 1789 to 1976 massive to near-massive lenses of sulfides have been mined for iron, copper, and iron sulfide for the manufacture of sulfuric acid. About 90% of the ore is pyrrhotite with the remainder largely sphalerite, chalcopyrite, and scattered galena. The sulfide lenses are conformable to the enclosing metasedimentary mica schist and gneiss of the Precambrian Ashe (Lynchburg) Formation and occur in a NE-trending zone 17 miles long. The deposits are considered to be synsedimentary pyrite, related to volcanigenic processes, later metamorphosed to pyrrhotite. Minor metavolcanic rocks occur within the ore zone.

The leveled top of the dumps consists of unsorted schist fragments and fines mixed with goethite and poorly soluble sulfates like jarosite. This surface was limed to counteract a pH of 2.5-3.1 and seeded with grass and pine. Drainage underneath the dumps, continues, however, because of the presence of a former stream bed, now completely covered. Soluble heavy metal sulfates continue to drain from the raw east tailing slopes into the mine run (Red Branch) which empties into Chestnut Creek about one half mile to the east. Sulfates identified on the eastern tailing slopes include: coquimbite, rozenite, copiapite, pickeringite, melanterite, ferrohexahydrite, szomolnikite, and chalcanthite. These more soluble sulfates are subject to metal flushing during heavy storms, then build up in dry periods. Iron hydroxide is precipitated in Red Branch by oxidation of ferrous sulfate to ferric sulfate and hydrolysis during dry periods. Iron flocculent ("yellow boy") is largely removed during heavy storms scouring. Simple, physical mass-transport of dump derived sediment is shown by an almost identical iron average ($x = 13.8\%$ Fe, range 7-20) for 17 dump samples and 5 stream sediments (-80 + 230 mesh) from Red Branch with 14.8 - 16.4% Fe. Chestnut Creek near-bank stream sediment 200 feet below Red Branch contained 2.1% Fe and 2.9% above Red Branch, normal background values for the Piedmont. Dilution of other metals from Red Branch sediment were: Cu from 850 to 44 ppm downstream (8 ppm upstream); Zn from 450 to 80 ppm downstream (41 ppm upstream); Pb from 260 ppm to 17 ppm downstream (19 ppm upstream).

Red Branch water contains 5,000 ppm Fe and ranges in pH from 2.8 to 3.5 at entrance to Chestnut Creek, with up to 43 ppm Zn, 73 ppm Mn, 2.4 ppm Cu, 0.37 ppm Pb. Red Branch drainage except during storms, is minor and rapidly diluted. High heavy metals and low pH are sharply confined to a 5 foot wide strip out of a total width of 65 feet in Chestnut Creek. The acid bank strip 300 feet downstream had increased to a pH of 6.4 compared to 6.8-7.0 outside strip; Fe, 13 ppm, 1 ppm or less outside; Zn 0.18 ppm, 0.02 ppm outside; Cu, 0.02 ppm. n.d., 0.02 outside; Mn, 1.1 ppm compared to n.d. to 0.13 ppm outside strip. Pb n.d. in plume or stream.

Further drainage from underground workings was formerly provided by a half mile conduit, Ingram Tunnel, which drained north into Chestnut Creek from the 350 foot mine level, until it was sealed with concrete in 1977. Chestnut Creek directly below Ingram T. showed minimal discharge, probably from metal-saturated soil and waste, not from the tunnel. Water values at bank were 3.5 ppm Fe compared to 2.4 to 2.6 up, down, and cross stream and pH 5.6 at bank with 6.4 up, down, and cross stream. Allied Chemical Company is currently considering an additional proposal for reclamation by impoundment of Red Branch headwaters and recirculation by pumping them back to the open pit, eventually filling the now-sealed underground mine.

RECLAMATION OF STEEPLY SLOPING TERRAIN IN COALFIELDS

H. G. Goodell
Department of Environmental Sciences
University of Virginia

The federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87) attempts to minimize the adverse social, economic and environmental effects of mining operations. The legislation acknowledges that, because of the wide diversity of climatological, ecological and geological conditions in areas subject to mining, the primary responsibility for "developing, authorizing, issuing and enforcing regulations for surface mining and reclamation operations subject to this Act should rest with the states (Sec. 101f)." Among the environmental protection and performance standards (Sec. 515) provided by the legislation is the backfilling with spoil so as to completely cover the mine high wall, thus returning the site to the original contour. However, variances to the reclamation guidelines are allowed if these alternatives offer equal or improved environmental, hydrologic, ecologic and/or land use conditions. The Virginia Coal Surface Mining Control and Reclamation Act of 1979 (45.1-226) accepts the federal reclamation standards while providing for their regulation and administration by the Commonwealth.

In southwestern Virginia the steep, geomorphologically mature valleys are underlain by predominantly flat-lying Pennsylvanian strata which consist of shales, coal and thick bedded competent subgraywacke sandstones. These sandstones comprise the high walls of the open-cut mines where the coal is taken from a series of benches or terraces working back from the crop and following the contour along the slope. The benches are sloped back to the high wall. Mining ratios are usually no less than 10:1 which generally results in high walls of 40 to 60 ft., although high walls of up to 150 ft. occur. Prior mining practices allowed spoil to be placed over the edge of the bench followed by hydroseeding of the entire mine workings. The coal, shale and sandstones are usually low in sulfur and offer no geochemical impediment to a normal ecological floral succession even on the spoil slopes. The grassy benches provide a maximum of ecological habitat diversity as well as choice locations for public works, agriculture (including tree farming and grazing), and recreation. The sandstone high walls are visually attractive and offer new scenic alternatives in otherwise steep hilly terrain covered with mixed conifers and hardwoods. Hydrologically the unforested benches do contribute to the "flashiness" of flooding, particularly in the first order streams.

In contrast, the return-to-contour high wall fills of the new federal legislation offer maximum exposure of disturbed earth at slopes near the angle of repose to sheet wash erosion, circular slope failures, and slumping. Effective stabilization of these slopes will be prohibitively expensive. However, even if stabilized the hydrologic characteristics of the recontoured fills are even worse than those of the benches and should promote even more intense flash flooding.

Virginia's Surface Mining Control and Reclamation Act should be revised so as to offer maximum flexibility in mining and reclamation while at the same time providing environmental safe guards. The mine and reclamation plan submitted as a part of the permitting process should be judged by a panel of ecological, geological, hydrological, and land-use experts as to its soundness and feasibility given all of the physical and biological constraints of the mine site. Minimization of surface exposure and adequate drainage of mine tailings is desirable, particularly if these constitute an environmental hazard. Mine cuts on steep slopes are not categorically bad if the high walls are stable and if the benches and slopes are hydroseeded and reforested.

USE OF MYCORRHIZAE ON PINE SEEDLINGS IN COAL FIELD RECLAMATION

J. D. Artman - Pathologist
Virginia Division of Forestry

Mycorrhizal organisms are beneficial fungi that infect plant roots and yet enter into a symbiotic relationship with the host plant. The plant roots serve as a place for the fungus to live and reproduce. The fungus enables the plant to survive in areas where growth may normally be limited due to pH, high soil temperature, poor site quality, etc. This paper covers one effort in Virginia to "tailor" pine seedlings to a specific site.

In spring, 1974, one-year-old loblolly pine seedlings with and without **Pisolithus tinctorius** (Pt) ectomycorrhizae were planted in 12 isolated blocks on a coal strip in southwest Virginia where previous attempts at reclamation had failed. Block pH values averaged 3.4. Survival differences after two growing seasons were statistically significant, 70% versus 90% for Check and Pt seedlings, respectively. Such differences may or may not be of practical significance depending upon original densities and objectives

for a given site. Height differences at planting (Pt seedlings were 29% taller) were essentially maintained for the first three growing seasons after outplanting, then increased to 40% and 41% during the fourth and fifth seasons, respectively. Stem diameters were not recorded at planting time, but diameter differences have averaged 25%, 43%, 42%, 44% and 44% after 1, 2, 3, 4 and 5 growing seasons, respectively, with the Pt trees being consistently larger. After 5 years, Pt trees had a 190% volume advantage over the Check trees.

Check trees have always appeared chlorotic and were extremely so after the 1976 growing season. During the winter of 1976-77, winter burn was severe. The average Check tree had 26% of its foliage burned; treatment trees averaged 6% burn. The more severe burn on Check trees probably held back growth in 1977 and allowed Pt trees to increase their advantage. After the 1978 season, differences in tree color, needle length, foliar density and total growth were dramatic.

AUSTINVILLE MINING — 1756 TO PRESENT

E. T. Weinberg
The New Jersey Zinc Company

The Austinville Mine is located 75 miles southwest of Roanoke, Virginia, in Wythe County. It constitutes the only active metal mine in the state and has enjoyed 223 years of activity. During that time, it has progressed from a handicraft, near-surface, labor-intensive industry to one that is mining at depth and is quite dependent on sophisticated machinery for ore extraction and beneficiation. The mine workings extend for approximately six miles along strike and one-half mile across strike. Levels are cut every 100 feet vertically down to the 1200 foot level. Entrance is mainly from two vertical shafts, although subsidiary ventilation shafts, adits, and mobile equipment inclines provide necessary escapeways and airways.

Austinville is an atypical, stratabound zinc-lead deposit in that it is located in a folded and faulted environment. Its host rock is the Shady Formation of lower Cambrian age, which is a dolomite in most of the mine area. Mining covers a stratigraphic interval of approximately 1400 feet and extends from near surface to the lowest mining level, 1100 feet below the shaft collar.

Production has been characterized by two separate periods with large qualitative and quantitative differences. The early period was one of desultory production, low tonnages, and high grades. Prior to 1870, mining was almost exclusively for lead. Between 1870 and 1924, this period of low production continued but included the oxidized zinc mineral, hemimorphite. After 1924, production rose rapidly with the advent of the flotation process for the concentration of the sulfide minerals and has included over 90% of the unknown ore to date, approximately 29,000,000 tons. Current production is approximately 500,000 tons per year containing 3% zinc, 0.4% lead.

The ore itself occurs in tabular lenses within discrete, favorable zones in the middle and lower Shady. These lenses average perhaps 400 feet in strike length, 100 feet in dip length and 10 to 30 feet thick. Individual lenses can and do vary considerably from the average. Some lenses are stacked vertically and can be mined concomitantly. Some, which are continuous for long strike distances, are especially amenable to mining by trackless mobile equipment. The smaller lenses still are best mined using jackleg drills and slushers. All long haulage is by rail to an underground crusher. The ore, crushed to a maximum four-inch size, is hoisted by automatic, six-ton skips to the surface where it is processed in a 2,500 ton per day flotation mill. The products are concentrates of zinc sulfide averaging 61.5% zinc metal, concentrates of lead sulfide averaging 75% lead metal, and finely-ground agricultural, dolomitic-limestone.

Ever since extensive mining has been pursued at Austinville, water in excess has been a problem. We are currently pumping about 13,000 gallons per minute or 19,000,000 gallons per day. Every new level or major development into new ground is equipped with water-tight, "bulkhead" doors which can be closed to protect the shafts and other mining areas from sudden inflows. The rock itself is generally impermeable except along fault or joint systems which provide the major hazards at depth. Oxidation along some of these fault systems has been observed as deep as 1,100 feet beneath the surface.

About this point in any discussion of Austinville, someone is sure to raise the question of mine life and reserves. It is not practical to refer to specific reserve figures since they are quite sensitive to economic factors. Austinville's current grade and tonnage targets, however, place it in a marginal economic category. The current squeeze between low base metal prices and high operating costs can only accelerate the tendency to premature closure before the real exhaustion of metal-bearing tonnages. Operating costs are especially responsive to energy and labor rates as well as to environmental requirements.

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KYANITE MINING IN VIRGINIA

G. B. Dixon, Jr.
Kyanite Mining Corporation

The mining of kyanite began for the first time in the history of the world in Prince Edward County, Virginia. The deposits were prospected by a Virginian, Mr. Joel Watkins of Charlotte County, during the 1920's. Mining has been discontinued in Prince Edward County and the quarry is being returned to grazing and forest land. The largest kyanite mining company in the world today has its headquarters in Buckingham County, Virginia and employs two hundred miners at the present time. There have been no serious environmental problems at this plant in its forty years of existence.

The world production of kyanite is estimated to be 200,000 tons of which 90,000 are produced in Virginia. Approximately 40 percent of this kyanite is exported through the port of Hampton Roads and brings money from other countries to Virginia. Reserves of kyanite in Buckingham County will last several decades. There are several potential prospects, both to the north and west of the present open-pit mining operation at Willis Mountain. Blasting is followed by crushing materials ½″ in three stages. The primary crusher is a 50 x 60 jaw crusher. The processing is accomplished by milling in a 500 horsepower, 9½ x 12 rod mill followed by fatty acid floatation in 300 Cu. Ft. cells and then by drying in a rotary dryer.

A new high intensity wet magnetic separator is now being used to remove iron contamination additional processing includes calcining at 3,000°F and size reduction to -325 mesh. The calcined kyanite is called mullite and this material is used for operations where the expansion characteristics of kyanite are not desired. Kyanite and mullite materials find wide use in the refractory and ceramic industries. The largest portion of kyanite is used in making brick for rotary kilns and furnaces. Some new applications are being developed in manufacturing stainless steel and fiber insulation. In future years kyanite in Virginia may become the source of aluminum. The many uses of kyanite may be able to contribute to the solution of many of the complicated problems of this nation.

SCHEDULED MEETINGS

May 2 - 4 Eastern Section, National Association of Geology Teachers, New Kensington, Pa. (Jesse Craft, Dept. of Geology, Kent State University, Kent, Ohio 44242) Theme: Geologic hazards in the urban area.

May 13 - 16 Virginia Academy of Science at the University of Virginia in Charlottesville. The Geologic Section will be held on Thursday, May 15. (Contact: Charles Bartlett, 102 South Court, Abingdon, Virginia 24210).

June - July Environmental workshops pertaining to geology, soil and water, marine life, forests, and wildlife will be held in the following locations:

VPI & SU	June 17 - July 3
William & Mary	July 14 - August 1
Virginia State U	July 7 - July 25
Longwood College	June 16 - July 3

For more information regarding credits and scholarships for these three week courses contact: Virginia Resource - Use Educational Council, c/o Bernard L. Parson, Seitz Hall, Room 203, V.P.I. & SU, Blacksburg, Virginia 24061.

October 3 - 4 Virginia Science Teachers Conference in Fredericksburg (Teresa Myer, Department of Education, Box 6Q, Richmond, Virginia 23216.

November 17 - 20 Geological Society of America annual meeting in Atlanta. (Contact GSA headquarters, 3300, Penrose Place, Boulder, Colorado 80301).

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GEOLOGIC RESEARCH IN VIRGINIA

A survey of current geologic investigations in Virginia conducted in spring 1980 is compiled below. The tabulated data include titles, types of geologic research, investigators, and contact addresses. The projects were grouped into two categories based on reported aerial extent: regional projects and projects involving county or quadrangle areas. Only locations of quadrangle projects are indicated on the index map. If there are additional entries for the project list, please advise the Division. A key to abbreviations and numbers follows the listings. Additional project information can be obtained from the researcher.

REGIONAL PROJECTS

EAST OF BLUE RIDGE

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Yorktown fossil catalog	13	Campbell	DMR	IP
Stratigraphy & structure SW piedmont	16, 17	Conley	DMR	80
Geophysical characteristics Culpeper Richmond Basins	8	Johnson	DMR	80
Aeroradiometric survey south-central Piedmont	8	Johnson	DMR	80
Geophysical characteristics Danville Basin & area	8, 10	Johnson	DMR	81
COSUNA Report Costal Plain	16	Rader	DMR	IP
Coastal Plain stratigraphy	16	Rader & Berquist	DMR	IP
Clay resources	12	Sweet	DMR	81
Gold mines & prospects	12	Sweet	DMR	C
Farmville coal basin	12	Wilkes	DMR	C
Radiometric survey of Triassic rocks of Northern Va. using thermoluminescence radiation desimetry.	3, 5, 6, 8, 12,	Seigel & Lindholm	GW	81
Basement configurations SE Virginia	1, 8, 10, 17	Sabet	OD	81
Chesapeake Bay earth science study	6	Staff	M	81

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Inner Coastal Plain tectonics mid-Atlantic states	10, 16, 17	Mixon	USGS-G	83
Cenozoic stratigraphy and structure Tidewater	5, 12, 16, 17	Newell	USGS-G	83
Regional aquifer system analysis (RASA)	1, 6, 9	Harsh	USGS-W	84
Land subsidence investigation southeastern Virginia Coastal Plain	1, 9, 16	Hopkins	USGS-W	81
Quaternary map Coastal Plain	2	Johnson	W/M	80
Geology selected field locations	2	Johnson	W/M	80
Stratigraphy Coastal Plain	10	Johnson	W/M	81
Coastal Plain salt water	1, 6, 9	Larson	USGS-W	80
Hydrology of the Culpeper Basin	1, 6, 9	Zenone	USGS-W	81
Geomorphic evolution Va. Piedmont	5, 6, 7, 10	Dunford-Jackson	VA	81
Blockfields Shenandoah Park	5, 7, 10	Hudson	VA	80
Fourier grain shape analysis Chesapeake Bay	1, 5	Boon	VIMS	81
Sediments and sediment budget lower Chesapeake Bay	5, 6, 7, 10,	Byrne & Hobbs	VIMS	80
Small tidal inlets Chesapeake Bay	4, 5, 7, 9	Byrne	VIMS	IP
Seasat data Chesapeake Bay	15	Munday	VIMS	IP
Fluid muds in Chesapeake Bay	4, 5, 6, 9	Nichols	VIMS	80
Cordierites	6, 11, 14	Armbruster	VPI	81
Thermal conductivity of Coastal Plain sediments	1, 3, 8, 16	Lambiase	VPI	80
Dinoflagellate studies, N. J. to Ala.	2, 5, 13, 16	McLean	VPI	IP

WEST OF BLUE RIDGE

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Brallier	3, 13, 14, 16	Ludegard & Samuels	A	IP
Keyser Formation stromatoporoids northern Valley	13, 16	Stock	A	IP
Lee County fracture trace	15, 17	Gathright	DMR	C
Coal sampling & analysis	1, 3	Henderson	DMR	IP
Karst mapping	7	Hubbard	DMR	IP
COSUNA Report Valley & Ridge	16	Rader	DMR	80
Fluvial systems Massanutten sandstone	16	Fichter & Dotson	JM	80
Hydrologic modeling Shenandoah River Valley	5, 9	Sauvier	JM	IP
Post-Martinsburg Ordovician stratigraphy	16	Diecchio	NC	80
Subsidence in karst terranes, northern Valley	4, 5, 16	Davies	USGS-G	84

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Thrust fault deformation and hydrocarbon entrapment	3, 8, 17	Harris	USGS-G	IP
Stratigraphy and structural studies of Devonian black shales in Applachian Basin	3, 16, 17	Roen & Harris	USGS-G	IP
Hydrologic interactions between the ground-water and surface-water systems in coal mining areas of southwest Va.	6, 9	Hopkins	USGS-W	83
Geochemical modeling of process controlling mine drainage in southwest Va.	1, 6, 9	Hufschmidt	USGS-W	83
Echinodermata, Benbolt Fm	13, 16	Broadhead	T	84
Blockfields Shenandoah Park	5, 7, 10	Hudson	VA	80
Sedimentology Stonehenge Chepultepec Formations	14, 16	Bova & Read	VPI	80
Cleavage development SW VA	17	Gray	VPI	82
Cementation patterns Middle Ordovician ramp to basin facies	14, 16	Grover	VPI	80
Stratigraphy and paleoecology Bluefield Formation	13, 16	Hamphreville	VPI	81
Stratigraphy Martinsburg for SW Va	14, 16	Kreisa	VPI	80
Sedimentology Conococheague - Elbrook Formations SW Va	16	Koerchner & Read	VPI	80
Stratigraphy Hampshire Formation	14, 16	McClung	VPI	80
Sedimentology and development Knox unconformity	14, 16	Mussman & Read	VPI	80
Middle Ordovician ramp to basin facies	14, 6	Read	VPI	80
Evolution Cambro-Ordovician shelf	14, 16	Read	VPI	81
Community paleoecology Martinsburg Formation, SW Va	13, 16	Springer	VPI	81

OTHER PROJECTS

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Geology of the Roanoke 1:250,000 scale map	10	Conley	DMR	84
Geophysical characteristics of Blue Ridge	8	Johnson	DMR	IP
Metallic mines and prospects, Blue Ridge	10	Sweet	DMR	C
Virginia water-use data system	1, 9	Hopkins	USGS-W	IP
Planning study for the investigation of low-flow characteristics of Virginia streams	1, 5, 9	Prugh	USGS-W	80
Water quality & health	5, 6, 9	Hornberger	VA	81
Quantitative classification of Va. soils	5, 6, 7	Lent	VA	80
Study of some minerals	11	Mitchell	VA	81
Sorted patterned ground	7	Clark	T	80

PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Debris slides in Applachians	7, 15	Clark	T	81
Volatile molecules in channel structures	6, 11, 14	Armbruster	VPI	81
Refined optical measurements of minerals	11, 12, 14	Bloss	VPI	90
Community paleoecology	13	Bambach	VPI	81
Paleographic reconstruction & paleobiogeography	13	Bambach	VPI	83
Seismicity of Va.	1, 4, 5, 8, 17	Bollinger	VPI	IP
Gold in Virginia	6, 11, 12, 14	Craig	VPI	IP
U. S. oil and gas field reserves and geologic factors	3	Grender	VPI	IP
Analysis and modeling of energy supplies	2, 3	Grender & Rapopart	VPI	IP
Seismicity studies	8	Snoke	VPI	81
X-ray study minerals bonding with transition metals	11	Ribbe	VPI	85
Conversion kaolin to mullite	6, 11	Ribbe & Nakajima	VPI	82
Eustacy, paleoclimate	13, 16	McLean	VPI	IP

PROJECTS BASED ON COUNTY OR QUADRANGLE BOUNDARIES

COUNTY

Projects that extend into adjoining counties are indicated *

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Accomac				
Structural control meanders Coastal Plain rivers	7, 10, 15, 17	Drake	OD	81
Allegheny				
Stratigraphy of black shale in Tuscarora Sandstone*	3, 16	Diecchio	NC	IP
Stratigraphy & paleontology Upper Chemung & Hampshire Fms.	13, 16	McDonnell	NC	80
Stratigraphy Devonian Chemung-Brallier contact*	13, 14, 16	Lyke	NC	80
Silica Resources*	12, 14	Wilkes	DMR	80
Amelia				
Richmond coal basin*	13, 16	Wilkes	DMR	80

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Amherst				
Westhering and Thorium migration in Allanite-Monzonite bearing pegmatite	5, 6, 11, 14	Meintzer	VA	80
Augusta				
Trace metal adsorption by MnFe oxide coatings on stream pebbles with their use in mineral exploration*	6, 12	Robinson	JM	81
Silica Resources*	12, 14	Sweet	DMR	C
Bath				
Stratigraphy of black shale in Tuscarora Sandstone*	3, 16	Diecchio	NC	IP
Stratigraphy Devonian Chemung-Brallier contact*	13, 14, 16	Lyke	NC	80
Stratigraphy & paleontology of Upper Chemung & Hampshire fms*	13, 16	McDonnell	NC	80
Silica resources*	12, 14	Sweet	DMR	C
Bland				
Analysis of dome & basin structure*	17	Armstrong	VPI	81
Botetourt				
Regional structure*	10, 17	Bick	W/M	IP
Stratigraphy of black shale in Tuscarora Sandstone*	3, 16	Diecchio	NC	IP
Stratigraphy & paleontology of Upper Chemung & Hampshire fms*	13, 16	McDonnell	NC	80
Silica resources*	12, 14	Wilkes	DMR	IP
Buckingham				
Geochemistry volcanogenic deposits*	5, 6, 7, 9, 12	Good	DMR	IP
Caroline				
Taylorsville Triassic basin*	16	Weems	DMR	C
Carroll				
Appalachian massive sulfides*	11, 12, 14, 16, 17	Gair	USGS-G	IP
Environmental monitoring Gossan Lead	5, 6, 9	Good	DMR	C
Charles City				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Chesapeake				
Stratigraphy & paleoecology of the marine Pleistocene of SE Va*	13, 16	Spencer	OD	80

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Chesterfield				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Richmond coal basin*	3	Wilkes	DMR	80
Craig				
Computer analysis terrain*	5, 7	Grender	VPI	IP
Geochemistry stream sediments	11, 12	Halladay	DMR	80
Stratigraphy & paleontology of Upper Chemung & Hampshire fms*	13, 16	McDonnell	NC	80
Silica resources*	12, 14	Wilkes	DMR	IP
Culpeper				
Environmental geology & hydrology Culpeper Basin*	4, 5, 9	Froelich	USGS-G	81
Dickenson				
Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81
Dinwiddie				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Fairfax				
Environmental geology & hydrology Culpeper Basin*	4, 5, 9	Froelich	USGS-G	81
Fauquier				
Environmental geology & hydrology Culpeper Basin*	4, 5, 9	Froelich	USGS-G	81
Fluvanna				
Geochemistry stream sediments	6	Good & Fordham	DMR	C
Frederick				
Devonian Clearville siltstone stratigraphy & sedimentology*	16	Jolley	NC	80
Giles				
Quaternary stratigraphy & bedrock structural framework	8, 16, 17	McDowell	USGS-G	81
Deformation within Martinsburg Fm*	17	Mullenax	VPI	81
Goochland				
Geochemistry stream sediments	6	Good & Fordham	DMR	C
Richmond coal basin*	3	Wilkes	DMR	80
Grayson				
Environmental monitoring Gossan Lead	5, 6, 9	Good	DMR	C

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Green				
Catastrophic flooding of Rappahannock River Basin*	7, 9	Whittecar	OD	82
Hanover				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Taylorsville Triassic basin*	16	Weems	DMR	C
Henrico				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Richmond coal basin*	3	Wilkes	DMR	80
Highland				
Stratigraphy of black shale in Tuscarora Sandstone*	3, 16	Diecchio	NC	IP
Stratigraphy Devonian Chemung-Brallier contact*	13, 14, 16	Lyke	NC	80
Silica resources*	12, 14	Sweet	DMR	C
James City				
Cementation & diagenesis Yorktown Fm*	14	Benedict	W/M	81
Mineralogy and Ti content local clays for pottery analysis*	6, 11	Clement	W/M	81
Habitat development field investigations James River *	5, 6	Darby	OD	IP
Lee				
Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81
Possible paleoenvironmental equivalence of correlative lower Silurian rocks of Northeastern Tenn and SW Va *	16	Wagner	C	81
Loudoun				
Environmental geology & hydrology Culpeper Basin*	4, 5, 9	Froelich	USGS-G	81
Louisa				
Appalachian massive sulfides *	11, 12, 14, 16, 17	Gair	USGS-G	IP
Geochemistry volcanogenic deposits *	5, 6, 7, 9, 12	Good	DMR	IP
Madison				
Catastrophic flooding of Rappahannock River Basin *	7, 9	Whittecar	OD	82
Nelson				
Rockfish granodiorite geochronology	11, 14	Mose	GM	81
Channel changes from Hurricane Camille	5, 7, 9	Ponton	VA	81

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
Norfolk				
Stratigraphy & paleoecology of the marine Pleistocene of SE Va*	13, 16	Spencer	OD	80
Response of Elphidium excovatum to trace metal content, lower Chesapeake Bay *	5, 6, 13	Spencer	OD	82
Northampton				
Structural control meanders Coastal Plain rivers *	7, 10, 15, 17	Drake	OD	81
Orange				
Catastrophic flooding of Rappahannock River Basin *	7, 9	Whittecar	OD	82
Page				
Upper Ordovician Lower Silurian sandstones *	14, 16	Roberts	JM	80
Powhatan				
Richmond coal basin *	3	Wilkes	DMR	80
Prince George				
Identification of subsurface Triassic*	6, 11, 14, 16	Shomo	NC	80
Prince William				
Environmental geology & hydrology Culpeper Basin*	4, 5, 9	Froelich	USGS-G	81
Occoquan pluton geochronology *	11, 14	Mose	GM	80
Roanoke				
Silica resources*	12, 14	Wilkes	DMR	IP
Rockbridge				
Regional structure *	10-17	Bick	W/M	IP
Geology & geochemistry of Irish Creek tin district *	6, 10, 12	Good & Hudson	DMR	81
Stratigraphy & paleontology of Upper Chemung & Hampshire fms *	13, 16	McDonnell	NC	80
Silica resources *	12, 14	Sweet	DMR	C
Rockingham				
Paleoenvironments of the New Market-Lincolnshire formations	16	Fichter	JM	81
Devonian Clearville Siltstone stratigraphy & sedimentology*	16	Jolley	NC	80
Trace metal adsorption of Mn, Fe, oxide coatings on stream pebbles with their use in mineral exploration	6, 12	Robinson	JM	81
Russell				
Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81

COUNTY AND PROJECT TITLE	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
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Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81
Possible paleoenvironmental equivalence of correlative Lower Silurian rocks of Northeastern Tenn and SW Va*	16	Wagner	C	81
Shenandoah				
Paleoenvironmental interpretation of a portion of the Conococheague Fm*	16	Fichter & Cord	JM	80
Devonian Clearville Siltstone stratigraphy and sedimentology*	16	Jolley	NC	80
Trace metal absorption by Mn, Fe oxide coatings on stream pebbles with their use in mineral exploration*	6, 12	Robinson	JM	81
Spotsylvania				
Tectonics of northeast Va. Piedmont*	10, 14, 16, 17	Pavlides	USGS-G	80
Stafford				
Structural analysis metamorphic rocks near Fredericksburg*	14, 17	Robinson	JM	81
Tectonics of northeast Va. Piedmont*	10, 14, 16, 17	Pavlides	USGS-G	80
Suffolk				
Cementation & diagenesis Yorktown Fm*	14	Benedict	W/M	81
Tazewell				
Analysis of dome & basin structures*	17	Armstrong	VPI	81
Virginia Beach				
Stratigraphy & paleoceology of the marine Pleistocene of SE Va*	13, 16	Spencer	OD	80
Responses of Elphidium excovatum to trace metal content, Lower Chesapeake Bay*	5, 6, 13	Spencer	OD	82
Washington				
Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81
Wise				
Stratigraphy & paleontology Wildcat Valley Sandstone*	13, 14, 16	Kier	NC	81
Possible paleoenvironmental equivalence of correlative Lower Silurian rocks of Northeastern Tenn and SW Va*	16	Wagner	C	81
York				
Cementation & diagenesis Yorktown Fm*	14	Benedict	W/M	81
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QUADRANGLES

Numbers preceeding quadrangle names are keyed to the accompanying index map

QUADRANGLE & PROJECT	TYPE OF RESEARCH	RESEARCHER	ADDRESS	STATUS
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2-4. Upper Ordovician, Lower Silurian sandstones	14, 16	Roberts	JM	80
5. Bridgewater & Harrisonburg Q.	5, 10	Frischmann & Gathright	DMR	80
6. Elkton East & West Q.	5, 10	Gathright & Frischmann	DMR	IP
7. Massies Corner Q.	10	Halladay & Lukert	DMR	C
8. Massies Corner Q. Precambrian (?) pluton geochronology	11, 14	Mose	GM	81
9. Remington Q. Geology of Jurassic basalt flows north of the Rappahannock River, Culpeper Basin	8, 10, 17, 14	Awosika	GW	81
10. Occoquan Q, Occoquan pluton	11, 14	Mose	GM	80
11. Stafford Q. Structural analysis of metamorphic rocks near Fredericksburg	14, 17	Amenta	JM	85
12. Rollins Fork Q. Oak Grove stratigraphic Test	13, 16	Reinhardt	DMR	C
13. Mustoe Q., Systematics & paleoecology of Keyser Fm stromtoperoids	13	Holmes	A	80
14-15. Bath Alum, Burnsville, Mountain Grove, Sunrise, Warm Springs Q. Area geology of Muddy Run region central Bath Co.	10, 16	Whitehurst	NC	80
16. Mountain Grove, Warm Springs Q. Late Cenozoic history of Jackson River valley	7, 10, 16	Kite	JM	80
17. Mountain Grove, Warm Springs Q., Soils of Gathright Dam site	10	Sherwood	JM	80
18. Falling Springs Q., Late Cenozoic geologic history of Jackson River valley	7, 10, 16	Kite	JM	80
19. Falling Spring Q., Soils of Gathright Dam site	10	Sherwood	JM	80
20. Covington Q., Dolly Anne Rare II	6, 8, 10, 12	Lesure	USGS-G	81
21. Crozet Q., Freshwater Lake redox chemistry	5, 6, 11	Nordstrom	VA	80

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23. Mineral Q., Fluid inclusion studies, Julia deposit	6, 12	Feiss & Holland	NC	80
24. Mineral Q., Rare earths in the Cofer ore	6, 11, 12	Feiss, Ussler, Spruill	NC	80
25. Mineral Q., Contrary Creek acid mine drainage	2, 5, 6, 9, 11	Nordstrom	VA	IP
26-27. Mineral, Pendleton Q., Massive sulfides in Va.	6, 11, 12, 14	Craig	VPI	IP
28. Lake Anna West, Lake Anna heavy metals	2, 5, 6, 9, 11	Nordstrom	VA	IP
29. Lakeside Village Q., Columbia (Hatcher) Granite geochonology	11, 14	Mose	GM	80
30. Andersonville, Willis Mtn. Q., Geol. study	5, 6, 8, 10, 12	Conley	DMR	80
31. Montpelier Q., Mineralogy & petrology Montpelier Anorthosites	11-14	Clement	W/M	81
32. Ashland, Hanover Academy Q.	5, 10	Weems	DMR	C
33. Glen Allen Q	5, 10	Goodwin	DMR	C
34. Fine Creek Mills Q., State Farm pluton geochronology	11, 14	Mose	GM	80
35. Bon Air Q	5, 10	Goodwin	DMR	C
36. Richmond Q, Building Stones	2, 5	Phillips	DMR	80
37. Richmond, Earth Sciences	2	Johnson	W/M	80
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39. Dutch Gap, Drewrys Bluff Q.	5, 10	Upchurch	DMR	81
40. Claremont, Gressitt, Norge, Surry, Toano Q	5, 10	Berquist	DMR	IP
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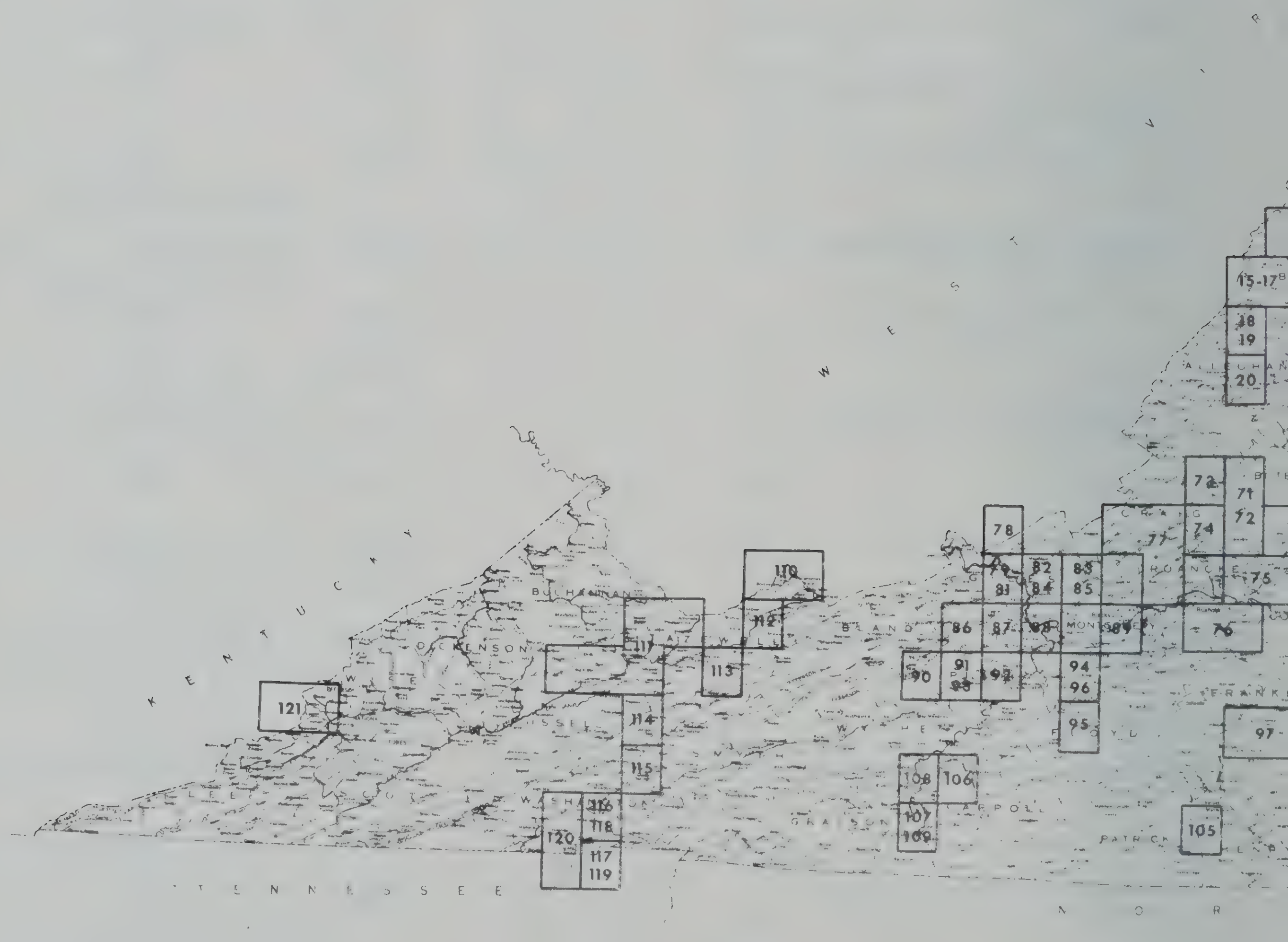
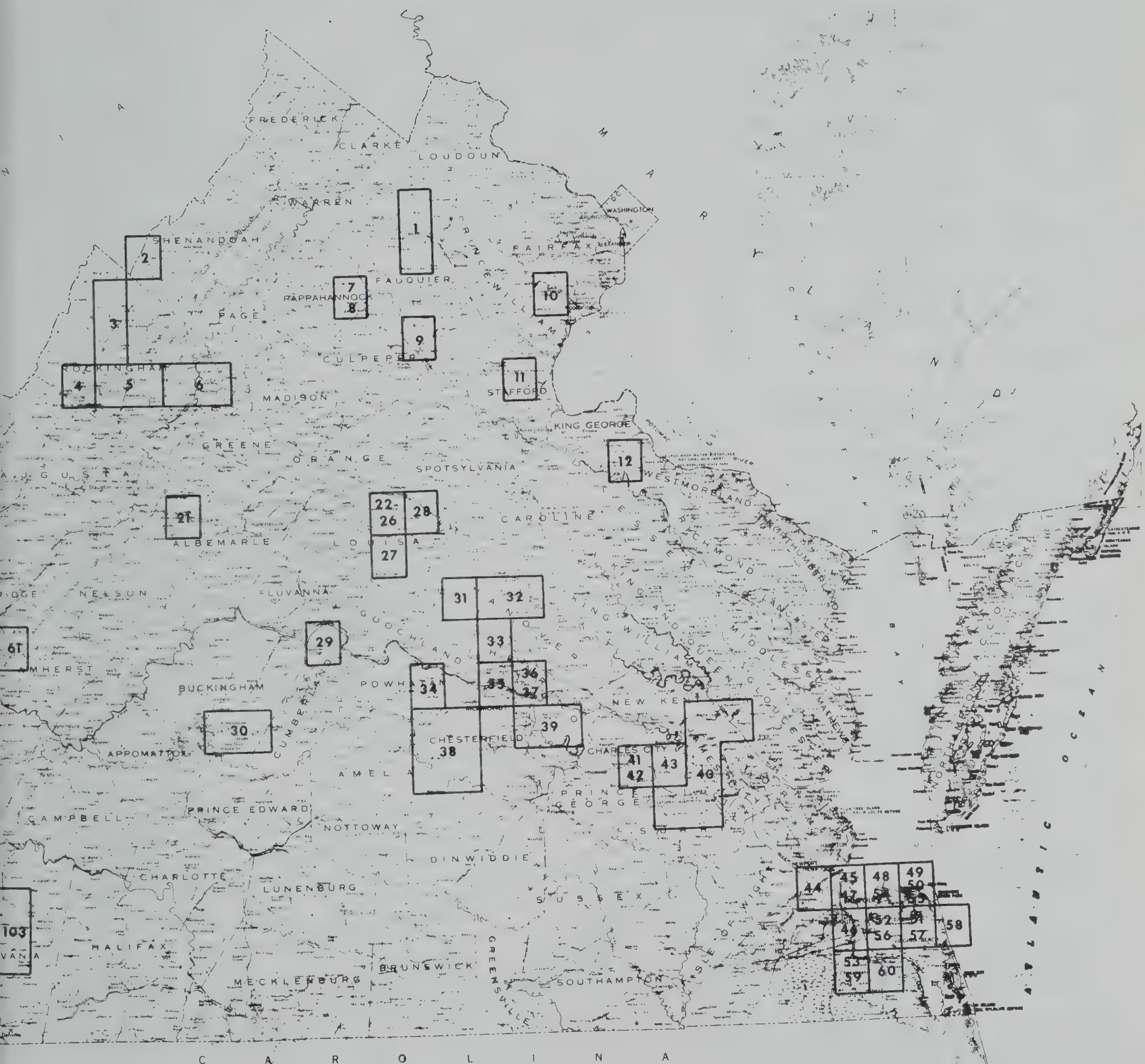


Index map of quadrangle projects with numbers keyed to listing. Regional and county projects are not included.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CHARLES CITY
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PRINCE EDWARD
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SUSSEX
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66-68. Buchanan, Glasgow, Natural Bridge, Q, Analysis fault zones	10, 17	Spencer	W/L	81
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70. Montvale, Villamont Q,	5, 10	Henika	DMR	80
71. Daleville, Oriskany Q, Sedimentology and petrography Diamond Hill Conglomerate	14	Benedict	W/M	81
72. Daleville, Oriskany Q, Heavy mineral analysis Fincastle Congl.	14	Benedict	W/M	80
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75. Roanoke, Stewartsville Q.	5, 10	Bartholomew	DMR	C
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80. Pearisburg Q.	5, 10	Bartholomew	DMR	81
81-83. Eggleston, Newport, Pearisburg, Q, Deformation within Martinsburg Fm.	17	Mullenax	VPI	81
84. Eggleston Q, Cleavage & thrusting of north end Southern Appalachians	17	Simon	VPI	81
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87. Staffordsville Q,	5, 10	Bartholomew	DMR	81
88. Radford North Q,	5, 10	Bartholomew	DMR	80
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97. Glade Hill, Rocky Mount Q.,	10	McCollum	DMR	C
98. Penhook Q,	10	Conley	DMR	IP
99. Penhook Q, Computer analysis terrain	5, 7	Grender	VPI	IP
100. Mtn. Valley Q,	10	Piepul	DMR	C
101. Callands, Sandy Level Q,	10	Berquist	DMR	C
102. Chatham, Pittsville Q.	10	Marr	DMR	C
103. Gretna & Spring Garden Q,	10	Conley	DMR	IP
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113. Tazewell South Q, Cleavage & thrusting at North End Southern Appalachians	17	Simon	VPI	81
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116-117. Abingdon, Shady Valley Q	14	Benedict	W/M	80
118-120. Abingdon, Holston Valley, Shady Valley, Wyndale Q	5, 10	Bartlett & Biggs	DMR	C
121. Appalachia, Benham Q.	3, 10	Henderson	DMR	IP

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ABBREVIATIONS EXPLANATION

CONTACT ADDRESS

A - Dept. Geology & Geography, Univ. Alabama, Tuscaloosa, AB 35486
CI - Dept. Geology, Univ. Cincinnati, Cincinnati, OH 45221
OD - Dept. Geophysical Sciences, Old Dominion Univ, Norfolk, VA 23508
CL - Dept. Chemistry & Geology, Clemson Univ., Clemson, SC 29631
DMR - Division Mineral Resources, PO Box 3667, Charlottesville,VA 22903
GM - Dept. Chemistry & Geology, George Mason Univ., Fairfax, VA 22030
GW - Dept. Geology, George Washington Univ., Washington, D. C. 20052
JM - Geology Dept., James Madison Univ., Harrisonburg, VA 22807
M - Maryland Geological Survey, Merryman Hall, John Hopkins, Univ., Baltimore, MD 21218
MS - Dept. Physical Sciences, Morehead State Univ., Morehead, KY 40351
MW - Dept. Geology, Mary Washington College Fredericksburg, VA 22401
NC - Dept. Geology, Univ. North Carolina, Chapel Hill, NC 27514
R - Dept. Geology, Radford Univ., Radford,VA 24142
T - Dept. Geological Sciences, Univ. Tennessee, Knoxville, TN 37916
USGS-G - U. S. Geological Survey, Mail Stop 953, Reston, VA 22092
USGS-W - U. S. Geological Survey, Water Resources Div., 200 W. Grace Street, Richmond, VA 23220
VA - Dept. Environmental Sciences, Univ. Virginia Charlottesville, VA 22903
VIMS - Va. Institute of Marine Science, Gloucester Point, VA 23062
VPI - Dept. Geological Sciences, Va. Polytechnic Institute & State Univ., Blacksburg, VA 24061
W/L - Dept. Geology, Washington & Lee Univ., Lexington, VA 24450
W/M - Dept. Geology, College of William & Mary, Williamsburg, VA 23185

STATUS/ESTIMATED COMPLETION DATE

C - Completed
IP - In Progress

RESEARCH CATEGORY

1. Data processing
2. Earth Science teaching
3. Energy resources
4. Engineering geology
5. Environmental geology
6. Geochemical
7. Geomorphic
8. Geophysical
9. Hydrology
10. Mapping
11. Mineralogy
12. Mineral Resources
13. Paleontologic
14. Petrology
15. Remote sensing
16. Stratigraphic
17. Structural

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PROCESSES OF GOLD RECOVERY IN VIRGINIA

Palmer C. Sweet

About 98,600 troy ounces of gold were produced in Virginia from 1804 through 1947, when gold was last mined in the State (Sweet, 1980). During this 144-year-long period, processes of recovering gold changed in response to the need to use leaner and deeper ores and to the progress of technology. Early mining was in placers or in oxidized, near surface, lode deposits. As these reserves were exhausted, deeper lode or vein deposits were mined. It was estimated that in 1837 a profit-making gold mine had to yield a dollar for every bushel (about 100 lbs., 45.0 kg) of rock processed; the cost of mining 100 pounds of rock in 1837 was about 30 to 35 cents (Silliman, 1837, p. 106, 123). Gold that must be mined by underground methods is costly to produce because shafts and drifts must be constructed, the ore is generally in hard rock, and the rock commonly must be pulverized before recovery processing begins. By contrast, placer deposits can be worked by hand-shoveling, sluicing, or dredging the ore materials, which are then ready for processing without further treatment.

RECOVERY METHODS USED IN PLACER DEPOSITS

Much of the early recovery from placer deposits was by pan, but the success of this process was limited in two ways. First, gold recovered with the pan was chiefly only the coarser fraction of the gold particles; much fine and float-gold was carried off along with the gravel and water. Second, the amount of gravel that could be processed was small—even by those who mastered the art of panning. Only the richest deposits were profitable to work by this simple, direct method. Placers were mined in Virginia around 1832 at the Belzoro and Collins mines in Goochland County, the Whitehall mine in Spotsylvania County and the Grasty tract and Vaucluse areas in Orange County and placers were mined as late as 1935 in Prince William County.

Two types of pans (Figure 1) were commonly used in placer mining, the standard metal pan and the batea. The standard pan has a varied diameter, with the maximum being about 16 inches (41 cm), and is about 2 inches (5.1 cm) deep; and "sides" slope at about 45 degrees. These pans are generally made of

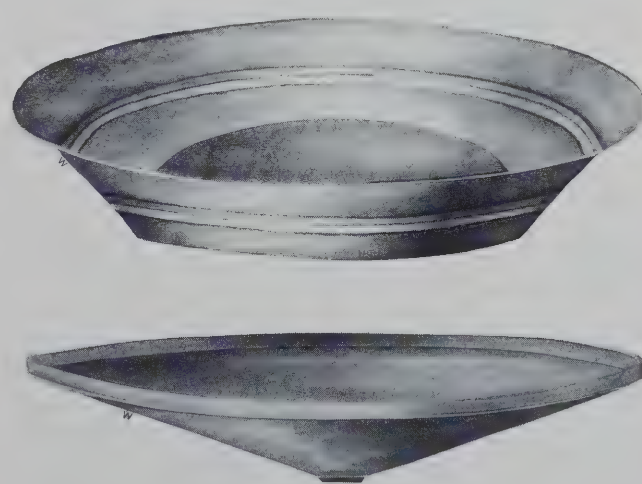

Figure 1. Two types of gold pans commonly used in placer mining, standard metal pan (top) and the batea (bottom).

sheet steel and the rim is crimped over a heavy iron wire for stiffness (Taggart, 1945, sect. 11, p. 56). The batea has a greater diameter than the standard pan and the sides slope at a lower angle giving the pan the shape of a flattened coolie hat. Heavy minerals are concentrated at the narrow center of the pan. Initially, the batea was early made of wood, but later steel was used.

Pans were better used for prospecting than for mining and recovery. When the richer placers were depleted, these crude implements were discarded in favor of mechanical devices capable of processing greater amounts of gravel.

The "cradle" or "rocker" (Figure 2) was one of the first devices used instead of the pan. Rocker-washing devices of varied designs had screens or grates for sorting the material. The screen in the hopper was commonly about 20 inches (50.8 cm) on each side with ½ inch (1.3 cm) openings. The finer materials, which contained the gold, were washed by water onto an inclined apron. The apron was

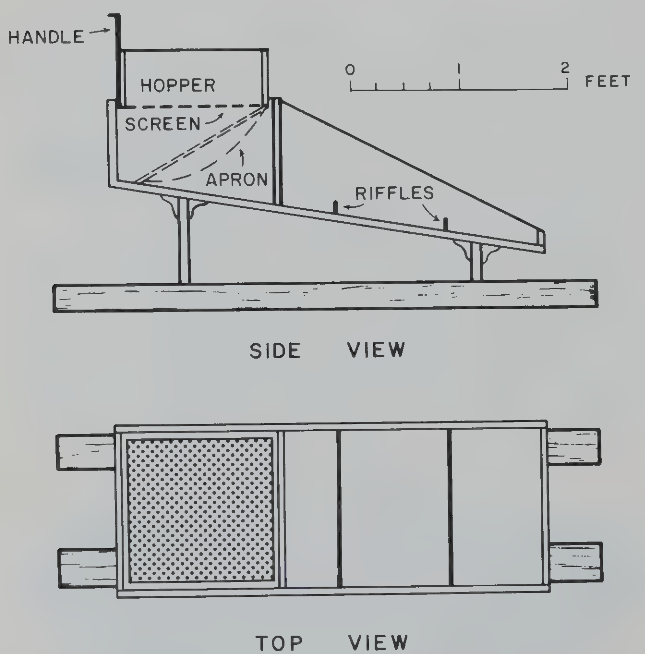

Figure 2. "Cradle" or "rocker" (after von Bernewitz, 1943).

commonly covered by canvas, blanket or corduroy to catch the gold; riffles below the apron also helped to catch the gold before it reached the head of the rocker. A quantity of water equal in weight to about four times the weight of the gravel processed was needed to separate the gold. The output of the cradle was small because the hopper had to be emptied each time the finer material was washed through the screen; the cradle was an inefficient machine.

Cradles, and also sluices, were utilized at the Belzoro, Bertha and Edith, and Collins mines in Goochland County and probably at many other placer deposits in Virginia in the 19th century (Taber, 1913, p. 141, 143).

The "tom" or "long tom" (Figure 3), another early device, was a more productive machine. It was made of two screened boxes and an inclined channel or flume, which sloped about one inch/foot (one cm/12 cm). The lower end of the upper box was at a 45

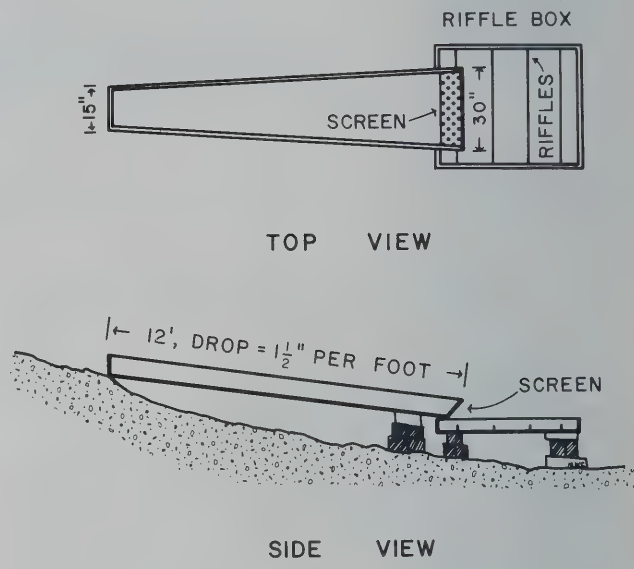

Figure 3. "Tom" or "long tom" (after von Bernewitz, 1943).

degree angle and was covered with a grating that retained the larger particles (mesh size was between ¼ and ¾ inches, 0.6 and 1.9 cm). Below the grating was a second box whose bottom surface contained riffles. The device could be operated continuously and production achieved by its use was relatively high. One or more men fed gravel into the upper box of the tom, and another stirred the gravel, broke up any clay, and discarded the particles that collected at the grating. Two men could wash five times as much gravel with a tom as with a cradle (Christiansen, 1974, p. 88-89), but the tom, like the cradle, was useful only where the gold was fairly coarse because in processing most of the fine gold was lost. After the particles were thoroughly sorted and washed, mercury sometimes was poured along the riffles to trap the gold by amalgamation (see later section for discussion on processes of amalgamation). Sometimes, pieces of blankets were laid between the riffles to trap the finer gold.

Sulfide minerals, which commonly occur with gold in placer deposits, must be removed before amalgamation processing. An early method used to

separate sulfides and gold in placer deposits was gravity concentration. This technique was used on coarse ores that contained too much sulfide gangue for immediate mercury amalgamation. One type of gravity concentration used was "corduroy tabling." In this process a mixture of gold ore and water was washed over a sloping surface covered with corduroy cloth, which retained the gold. This technique was effective in concentrating sand-size or larger gold particles, but a large fraction of the fine materials was lost. Corduroy tabling was utilized around 1913 at the Young American mine in Goochland County, (Taber, 1913, p. 119).

Another method of gravity concentration used was jigging, a process which utilizes the pulsating motion of water to separate ore from the larger, but lighter, grains of gangue. The gold itself is stratified by grain size during the process; coarser gold is at the bottom and finer is at the top. One type of jig, the Denver mineral jig, is a box with a screened bottom. A diaphragm is used to send pulses of water through the box; a series of pulsations separates the ore according to grain size and weight. A Denver mineral jig was used by the Moss Mining Company in Goochland County (Sweet, 1971, p. 27). As late at 1937 two jigs were utilized in the concentrating mill at the Bull Neck (Kirk) mine in Fairfax County (Ulke, 1937, p. 373).

Still another method of gravity concentration is sluicing, which uses water flow through a box (or trough) with riffles to separate the gold. Sluices were operated at most of the earlier placer gold deposits in Virginia, especially in Goochland, Orange and Spotsylvania counties.

RECOVERY METHODS USED IN LODE DEPOSITS

Crushing techniques: The majority of the ore recovered from veins must be crushed before any further refinement or recovery can be accomplished. The crushing has been done in a variety of ways, all based on the hand-held mortar and pestle. An early method employed a large rock tied firmly to a pole which was supported by a crutch made from a forked tree. One man raised the heavy rock while another kept the ore under it so that the rock could be dropped time after time to complete the crushing process. Crushing of ore at the Tellurium mine in Goochland County in 1834 was accomplished with heavy, hand-operated pestles and wooden mortars lined with iron (Taber, 1913, p. 153). This crude hit and miss method gave way to the arrastra.

Basically, an arrastra was a circular pit or container about 2 feet (0.6 m) deep, and 10 to 20 feet (3.0 to 6.1 m) or more in diameter. The sides and bottom were grinding surfaces made of crude, cut or dressed stone, or, uncommonly, of fitted wood, Grinding was accomplished by causing a 400 to 500 pounds (180 to 225 kg) rock to pass over the ore. The machinery consisted of a boom attached to a revolving pole set in the center of the arrastra. A mule at one end of the boom walked around the outside of the arrastra and the rock at the other end was dragged across the ore and the grinding surface. To "charge" the arrastra, ore was crushed by hand to the size of pigeon eggs (about 1 inch (2.5 cm) long dimension) and placed in the pit. Such an arrastra was utilized at the Tellurium mine in the late 1830's (Taber, 1913, p. 153).

The Chilean mill developed from the arrastra and differed from it by having grinding wheels, made of stone or iron, in the place of the heavy stone. More a grinding than a crushing machine, the Chilean mill was commonly used to pre-grind ores for the arrastra (Christiansen, 1974, p. 91). In 1847, 6 large Chilean mills were in operation at the Vaucluse mine (Lonsdale, 1927, p. 81).

The next later development for crushing was the stamp mill. In this device heavy wooden stamp stems with iron shoes were used to crush gold ore placed on a cast iron die seated at the top of a concrete mortar. Most stamps were driven by a steam-powered pulley and belt. In some stamps the mortar was mounted on a heavy, metal anvil, which in turn rested on a large block of concrete. The weight of the shoes and of the stamps varied. The average cost of crushing by stream stamps was 15 to 30 cents per ton in 1907 (Taggart, 1947, Sect. 4, p. 87-89). A total of ten stamp mills were operated at the Belzoro, Grannison and Morgan mines in Goochland County in the middle 1800's, and other stamp mills were probably in operation in the County at that time (Taber, 1913, p. 140-142). Several individual units were sometimes incorporated into a battery of stamps; two abandoned batteries of five stamps each are present today at the Red Bank mine in Halifax County (Sweet, 1971, p. 31). The crushed ore was commonly further separated from gangue by amalgamation.

At the Vaucluse mine in Orange County, three stamps weighing between 350 and 380 pounds (157.5 and 171.0 kg) each were used. After each blow of the stamp, a mixture of finely stamped gold ore and water passed through horizontally moving runners, and through a small mercury-coated eye opening. Contact of the gold ore and water mixture with mercury produced amalgam from which the gold was subsequently recovered (Lonsdale, 1927, p. 81-82).

Chemical and floatational processing: Amalgamation, the process in which mercury or "quicksilver" alloys with gold, permits recovery of much

gold missed by physical methods. The process commonly is used in mines that are small and which extract a fine, high-grade ore. The ore must be free of sulfides and sufficiently coarse to allow it it settle in a flowing stream of water. The surface tension of the gold ore and water mixture must be low enough to allow mercury to wet and engulf it; some types of impurities can preclude the process. The gold ore must also be free of such contaminants as oil or grease because the oil may collect sulfides, clays, calcite, etc., which would prevent the gold from being captured by the mercury. Gold from oxidized areas, tarnished gold, will not amalgamate readily and gold coated with iron oxides will not amalgamate at all. Thus mercury is not generally useful in amalgamating placer deposits of gold, but copper-plate amalgamation was used at the Crawford placers in Prince William County around 1935 (Pardee and Park, 1948, p. 60).

Once the amalgam is formed, it is commonly thinned by the addition of more mercury in order to separate insoluble material by causing it to overflow its container. The amalgam is then filtered, either by squeezing it by hand through canvas or by a mechanical or hydraulic press. The gold-concentrating process is completed when the filtered amalgam is heated in a furnace or over an open fire. The much more volatile mercury is vaporized and the gold is left behind (Taggart, 1927, Sect. 14, p. 10-24). (Some gold miners placed the amalgam in a hole in a potato so that when the potato was heated above an open fire the mercury was burned off and a lump of gold was left in the potato. This process can be dangerous because the potato may explode and because mercury vapors are poisonous.)

Amalgamation was used in 1836 at the Busby mine in Goochland County and processing included straining amalgamated gold through silk to separate excess mercury before the amalgam was heated to drive off the mercury (Sillman, 1837, p. 103). Gold was also recovered by amalgamation in the 1830's from the Moss (Goochland County), Walton (Louisa County), Culpeper (Culpeper County), and many other mines in Virginia (Sillman, 1837, p. 105, 111, 118).

In a more advanced process of amalgamation than the ones described for the Vaucluse mine, copper plates generally ⅛ to ⅜ inch (0.32 to 0.95 cm) in thickness are used instead of bowls and runners. A film of mercury is attached to the copper plates over which the gold ore and water mixture is passed. A processing plant at the Red Bank mine in Halifax County utilized amalgamation plates in the early 1900's (Sweet, 1971, p. 31), but in this process some gold was lost in the slime, (the suspension of finely powdered ore in water that is too fine to settle out).

Figure 4. Roasting stack at the Grasty tract in Orange County.

The loss of gold in slime at many mines throughout the country led to the development of cyanidation in the 1890's.

Cyanidation is a leaching process in which gold and silver are taken into solution in potassium or sodium cyanide and then precipitated with zinc (Salisbury, 1964, p. 58). This process is widely used at mines that produce sizeable quantities of relatively low-grade gold ore. The gold should be clean and free of base-metal sulfides. Cyanidation is sometimes used as a secondary-recovery process after the coarser gold has been treated by gravity concentration and amalgamation. A cyanidation plant was in use at the Bertha and Edith mine in Goochland County in 1897 (Taber, 1913, p. 143). Cyanidation equipment was purchased by the Red Bank mine but was never used (Laney, 1917. p. 161). The process was used on about 1,000 tons of tailings with little success at the Franklin mine in Fauquier County in 1901 (Lonsdale, 1927, p. 79).

A different process is used on gold ores having a large amount of pyrite, but a small amount of base-metals. In such ores the gold may be combined in the crystal structure of pyrite or other sulfides. For

these impure ores, a flotation process, which is based on the unequal affinities of gold and sulfides for air or water, can be used. In this process, air is injected into a tank of water (flotation cell) to form bubbles and then the ore-water mixture is added. Non-wettable particles, including gold, have a greater affinity for bubbles of air then wettable ones, including sulfides. The bubbles, strengthened by a frothing agent and containing non-wettable particles, can then be skimmed off. By changing the reagents of the flotation process, the surface characteristics of the particles can be altered, which allows a variety of minerals to be collected (Salisbury, 1964, p. 57). A small flotation-cell was used at the Melville mine in Orange County in 1935 (Pardee and Park, 1948, p. 57). A concentrating (oil-flotation) mill having three flotation-cells was in operation at the Bull Neck (Kirk) mine in Fairfax County in November, 1937 where jig concentrations were put into the flotation-cells with an emulsifying dope of pine oil, copper sulfate and xanthate (Ulke, 1937, p. 371). In such operations wettable minerals collect in the bottom of the flotation-cell. The gold-sulfide concentrate, along with the inevitable minor amounts of gangue material, either is roasted and treated by cyanidation or is smelted. Either process eliminates the residual sulfides. Three of these old roasting stacks are still standing in Virginia; one is at the old Grasty tract in Orange County (Sweet, 1975, p. 2) (Figure 4), one is at the Melville (Rapidan) mine, Orange County (Sweet, 1971, p. 29-30) and the third is located on Wilderness Run in Orange County. The old Wilderness Run Chimney (brick roasting-stack) was operated by Colonel Stockton probably in the 1830's and 1840's (Figure 5).

Figure 5. Roasting stack at the Wilderness Run tract in Orange County.

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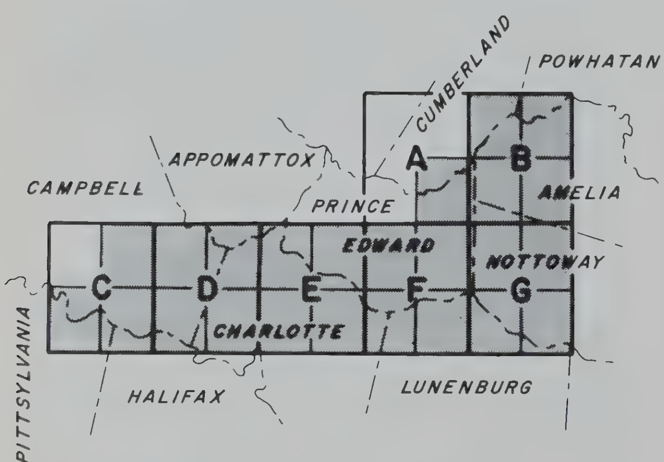
AERORADIOMETRIC MAPS — NORTH-SOUTH CENTRAL VIRGINIA

A detailed aeroradiometric survey that covers approximately 1550 square miles in parts of Amelia, Cumberland, Powhatan, Nottoway, Lunenburg, Charlotte, Campbell, Prince Edward, Appomattox, Halifax, and Pittsylvania counties is now available from the Division of Mineral Resources.

The survey was flown at 500 feet above terrain in an east-west direction with flight lines spaced one-half mile apart. A gamma-ray spectrometer with a 3500 cubic inch crystal system, calibrated using Department of Energy standards, was utilized to record the total counts per second as well as the individual responses of potassium, thorium, and uranium.

The survey data is presented as total count contour maps. Anomalous total count values are displayed on the total count contour map with a U



A FARMVILLE 15′	(Rice 7½′ quadrangle)
B JETERSVILLE 15′	(Cumberland, Ballsville, Deatonville, Jetersville 7½′ quadrangles)
C GLADYS 15′	(Gladys, Straight Stone, Long Island 7½′ quadrangles)
D BROOKNEAL 15′	(Mike, Red House, Brookneal, Aspen 7½′ quadrangles)
E CHARLOTTE C. H. 15′	(Madisonville, Abilene, Charlotte C. H., Eureka 7½′ quadrangles)
F KEYSVILLE 15′	(Hampden Sydney, Green Bay, Keysville, Meherrin 7½′ quadrangles)
G CREWE 15′	(Crewe West, Crewe East, Rubermont, Blackstone West 7½′ quadrangles)

Index for new aeroradiometric maps.

(uranium), K (potassium), or T (thorium). These "labeled" anomalies are greater than or less than 1.5 standard deviations above or below the area-wide arithmetic mean.

In addition to the contour maps, "stacked" profiles for each flight line in counts-per-second and parts-per-million are available. Separate flight path maps with fiducial and flight line numbers over a topographic base, and a computer listing noting all anomalies above or below one standard deviation for the survey is available.

The survey was performed in cooperation with the U.S. Geological Survey as a continuing effort to obtain geophysical measurements of rock characteristics throughout the Commonwealth. These current maps are useful in determining the distribution of rock types, especially where they are covered by soil, and in locating possible uranium and thorium occurrences.

Individual radiometric maps at a scale of 1/62,500 are available as ozalids for $2.00 each. Each individual flight line (as stacked profile) is available for $2.00. Flight path maps are $2.00 for each quadrangle. A 1/250,000 scale map of the total survey area is available on mylar for $25.00. The computer listing is $10.00. Add 4 percent State sales tax to orders with Virginia addresses.

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PUBLICATION 15

Geology of the Omega, South Boston, Cluster Springs and Virgilina Quadrangles, Virginia by R. D. Kreisa, 22p., 2 maps in color, 18 figs., 4 tables, 1980 - $9.00*

Rocks mapped are mostly metamorphic rocks of Precambrian age. Some Triassic sedimentary rocks, igneous dikes and Quaternary alluvium are also shown. Metamorphics are of the almandine-amphibolite grade and have been deformed into isoclinal folds. Mineral resources included crushed stone, sand, copper, graphite and clay materials. A roadlog to interesting geologic features is included.

PUBLICATION 16

Geology of the Abingdon, Wyndale, Holston Valley and Shady Valley Quadrangles by C. S. Bartlett, Jr. and T. H. Biggs, 39 p., 2 maps in color, 16 figs., 6

tables, 1980 - $9.50*

Mapped units include Cambrian, Ordovician and Mississippian age rocks and Quaternary alluvial, colluvial and terrace deposits. Structural features include complex faults and folds from the Greendale syncline to the Blue Ridge. Economic data on the usefulness of carbonates, shale, and iron ore are discussed. The constraints from rock and soil types on building construction and on liquid and solid waste disposal are described in an environmental geology section. Six measured sections are included.

PUBLICATION 17

Geology of the Massies Corner Quadrangle by M. T. Lukert and C. R. Halladay. One sheet in color, one interpretive cross-section, 1980 - $3.50*

Precambrian age metamorphic and igneous rocks, triassic dikes and Quaternary alluvium are shown. Faults and Folds within the Blue Ridge anticlinorium are indicated. Sources of sand and gravel are discussed. Reference localities for the major rock types are spotted on the map.

PUBLICATION 18

Geology of the Bon Air Quadrangle by B. K. Goodwin. One sheet in color, three interpretive cross-sections, 1980 - $3.50*

Mainly Paleozoic age igneous rock; Triassic coal measures, and sedimentary rocks, and dikes; and Cenozoic alluvium, sand and gravel are shown. Elliptical depressions occurring in some gravel areas are indicated. Economic materials include stone, coal, clay, sand and gravel. Geologic and economic factors which would be considered in land modification are indicated for each mapped geologic unit.

PUBLICATION 19

Gold in Virginia by P. C. Sweet, 77p., 31 maps, 16 figs., 2 tables, 1980 - $4.50*

Location and descriptive data by county is listed for 245 gold mines and prospects. Information on past gold production is given. Bibliographic references for further research of each are indicated. For those areas visited by the author portions of topographic maps are included with the mine or prospect spotted.

PUBLICATION 20

Geology of the Oak Grove Core by Juergen Reinhardt and others, in four parts, 88p., 45 figs., 1980. -$3.50*

Depositional features and environments for a continuously cored Cretaceous and Tertiary section near Oak Grove, Westmoreland County are described and interpreted. Included in the four part discussion are Tertiary lithostratigraphy, biostratigraphy of the Tertiary strata, Lower Cretaceous stratigraphy and lithologic description of the core. Distribution of fossil pollen in the Lower Cretaceous interval is indicated. Numerous illustrations show sedimentary features in the core.

*For publications mailed to Virginia addresses, add 4 percent State sales tax.

STAFF CHANGES

Effective June 1, 1980, Gary G. Lash of Allentown, Pennsylvania joined the permanent staff of the Division of Mineral Resources. Gary received his B.S. in geology from Kutztown State College, Pennsylvania in 1976. In 1978 he received his M.S. in geology from Lehigh University, Bethlehem, Pennsylvania. During this time he was employed by the U.S. Geological Survey and carried out structural studies in the Martinsburg Formation of eastern Pennsylvania.

Gary will receive his Ph.D. in geological sciences from Lehigh University in October, 1980. This work involved stratigraphic and structural studies of the allochthonous Hamburg Klippe and surrounding authochthonous rocks of eastern Pennsylvania and was completed while employed by the U.S. Geological Survey. Gary is married and has no children.

SCHEDULED MEETINGS

October 3, 4 Virginia Science Teachers Conference in Fredericksburg (Teresa Myer, Department of Education, Box 6Q, Richmond, Virginia 23216)

October 11, 12 Carolina Geological Society Field Trip in Danville area (Van Price, E. I. DuPont De Nemours and Company, Atomic Energy Division, Savannah River Laboratory, Aiken, South Carolina 29801)

November 1, 2 Virginia Field Conference: Tertiary and Quaternary Geology of the York-James Penninsula in Williamsburg (Bruce Goodwin, Department of Geology, College of William and Mary, Williamsburg, Virginia 23185)

November 6, 7 Virginia Association for Environmental Education at Skyland in Shenandoah National Park (Teresa Myer, Department of Education, Box 6Q, Richmond, Virginia 23216)

November 17-20 Geological Seocity of America annual meeting in Atlanta. (Contact GSA headquarters, 3300 Penrose Place, Boulder, Colorado 80301)

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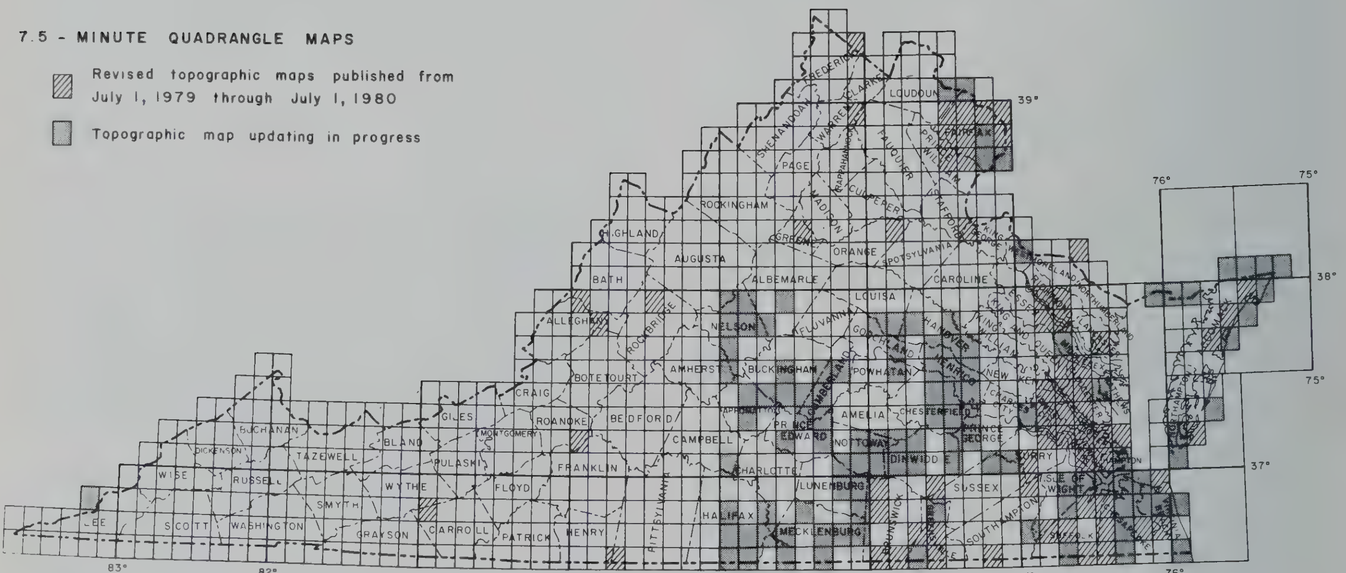

Revised 7.5 minute quadrangle maps published from July 1, 1979 through July 1, 1980:

Accomac
Alberta
Alexandria
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Austinville
Bloxom
Bowers Hill
Boykins
Buckhorn
Cape Henry
Cherry Hill
Chincoteague, West
Chuckatuck
Clay Bank
Clifton Forge
Corapeake
Danieltown
Dendron
Dunnsville
Emporia
Evarts
Fairfax
Falling Spring
Falls Church
Fentress
Garden City
Gasburg
Glouchester
Goshen
Gressett
Haynesville
Herndon
Hog Island
Holland
Independent Hill
Inwood
Irvington
Ivor
Lake Drummond
Lake Drummond, N. W.
Linden
Manassas
Mine Run
Morattico
Mulberry Island
Newport News, North
Norge
Northeast Eden
Occoquan
Passapatanzy
Piney Point
Pleasant Ridge
Poquoson, East
Poquoson, West
Saluda
Shacklefords
Ship Shoal Inlet
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SOFT-SEDIMENT DEFORMATION WITHIN CLASTS OF THE LIBERTY HALL FORMATION

E. Victoria Pritchard

The Middle Ordovician Liberty Hall Formation is comprised of basin and slope facies developed to the southeast of the Middle Ordovician carbonate ramp of the Appalachian basin. Near the Montgomery-Roanoke county border on the west side of Route 785, 8.7 miles (14.1 km) northeast of Blacksburg, Virginia, (Figure 1) there are excellent exposures of a portion of this formation. The locality is on the northwest limb of the southwest part of the Catawba syncline — a structure in the Pulaski overthrust sheet of the folded and thrust-faulted Valley and Ridge province.

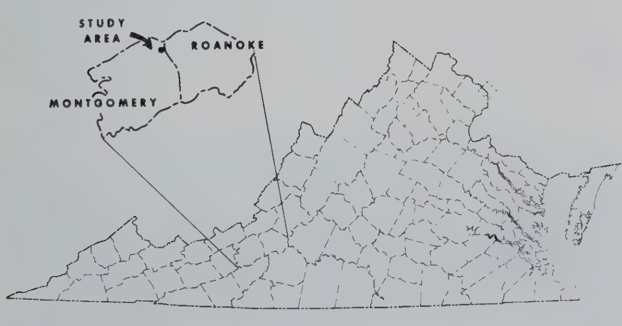

Figure 1. Index map

The Liberty Hall Formation, which ranges up to 1500 feet (450 m) thick in the Catawba syncline, overlies the Effna Limestone and locally grades laterally into biohermal and biostromal limestone buildups of the formation (Read and Tillman, 1977 and 1979). The basal 65 feet (20 m) of the Liberty Hall Formation at this locality consists mainly of interlayered dark-gray mudstone and medium-gray siltstone (Figure 2). Graptolites in the siltstone are preserved on well-developed bedding planes and the rocks show no post-depositional slump features. There is a three-foot-thick (1 m) lime mudstone exhibiting soft-sediment flowage about 55 feet (17 m) above the base of the Liberty Hall.

The siltstone is overlain by 20 feet (6 m) of non-graded, thinly bedded, dark-gray limestone with scour-and-fill structures. Directly overling this unit is a 15-foot-(4.5-m)-thick, highly folded section of

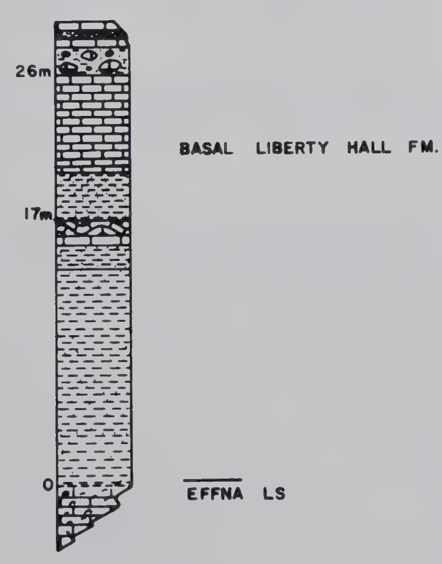

Figure 2. Section in lower part of Liberty Hall Formation.

Figure 3. Angular discordance at base of conglomerate-filled channel 85 feet (26 m) above base of Liberty Hall Formation.

dark-gray siltstone in a channel fill containing deformed cobbles. Beds in the ancient channel form a 15 degree angular discordance (Figure 3) with underlying beds. Axial surfaces of folds (Figure 4) formed in the channel deposits bear disharmonic relationships to each other.

Cobbles of dark-gray pelletal lime mudstone are enclosed in the channel fill of dark-gray, fissile, slightly pelletal siltstone (Figure 5). The cobbles, which exhibit ductile, soft-sediment deformation, are composed of dark-gray, homogeneous, pelletal

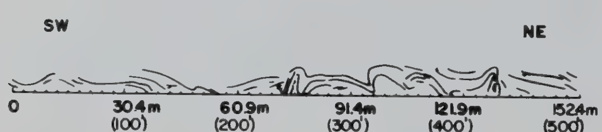

Figure 4. Sketch of disharmonic folding as seen along State Road 785 (vertical exaggeration: × 2; scale: 1 inch = 15.2 m).

lime mudstone. Interlayered light-and-dark-gray bands in the clasts result from admixtures of organic material to the clays; these bands define the deformational features observed in the cobbles.

The cobbles range in size from 1.5 to 10 inches (4 to 25 cm); shapes of the clasts range from subspherical to elongate. Degree of plastic deformation is correlated to cobble shape — sub-spherical clasts show complex responses whereas non-spherical ones exhibit little plastic deformation.

In thin sections clasts show a continuum of responses to the deforming stresses of motion. Initially, the internal layering was plastically deformed into tight "S" folds and tear-drop shapes (Figure 6). In some cases, faulting followed plastic

Figure 5. Conglomerate interval showing cobbles, which range in size from 1.6 to 10 inches (4 to 25 cm). The cobbles are enclosed in fissile siltstone.

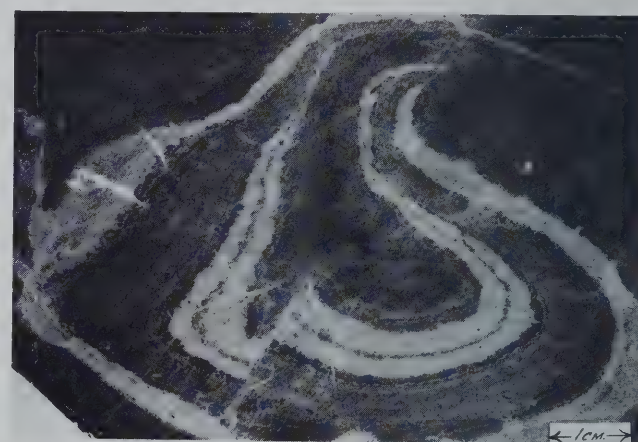

Figure 6. Interlayered bands of light- and dark-gray pelletal lime mudstone contorted into asymmetrical shapes as seen in prepared acetate peel. Bands in the lower left quadrant of photograph are offset as much as 2 mm.

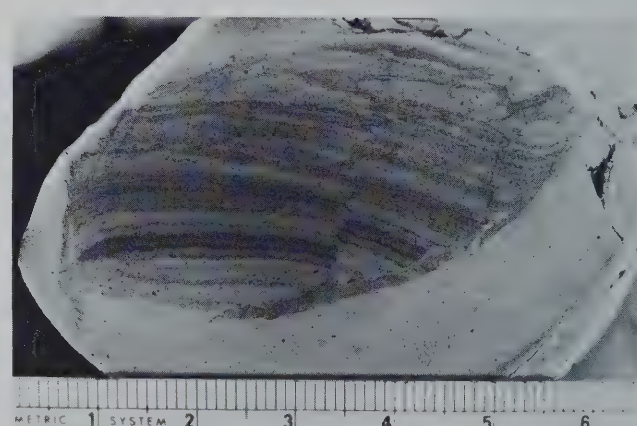

Figure 7. Faulted lime mudstone layers in sample with planar (noncontorted) layers.

deformation as continued downslope movement aided expulsion of water and extended the plastic response to the point of rupture (Figure 6). An example of brittle response is shown in Figure 7; the limestone was sufficiently cohesive to retain planar layering but ruptured during motion-induced stress.

Pelecypods of an unidentifiable species together with specimens of Cricoconarida, a class of probably pelagic Mollusca with a range from Lower Ordovician to Upper Devonian (Fisher, 1962), were found in one cobble. The assemblage, preserved undeformed, is typical of the Liberty Hall Formation.

Proposed mechanisms for triggering downslope movement include seismic shock and major storm waves (Cook and others, 1972). Although there was differential subsidence in the Catawba syncline during the Middle Ordovician (Lowry, 1974), the slumping described here may have had a different origin, movement of the muds could have been initiated because the depositional slope exceeded the angle of repose or because pore pressures sufficiently high for motion were achieved (Mountjoy and others, 1972). Instability led to the slumping of beds, as shown by the disharmonically folded zone sketched in Figure 4, and to the initiation of cobble transport, and cobble deformation. Penecontemporaneous slump features in similar facies have been reported in formations of the Middle Ordovician near Lexington and Marion, Virginia (Cooper, 1968) and near Harrisonburg, Virginia (Lowry and Cooper, 1970).

No azimuth for origin of the deformed cobbles in the Liberty Hall Formation is derivable from the observed data. They likely formed on gentle gradients on the margin of a carbonate platform of the Appalachian basin located northwest of the area. Development of the clasts is related to instabilities within the basin which culminated in failure and deformation of a discreet, 15-foot-(4.5-m-) thick sequence. The disharmonic nature of the deformed materials negates tectonism as the folding mechanism. The conglomerate clasts are probably intraformational, a conclusion supported by the observation that fossil pelagic forms typical of the Liberty Hall are in the clasts. Because the cobbles, enclosing siltstones, and immediately underlying rocks do not contain remains of benthic organisms, the beds probably do not represent a shoal provenance with good circulation. The undeformed state of the fossils in the clasts is evidence of short transportation and early lithification of the clasts.

I thank Professor W. D. Lowry for help with the field work and preparation of this paper. Professor C. G. Tillman helped in identifying fossils. George Grover, Jr., and R. Pfeil instructed me in laboratory preparation of samples and thin sections. Thanks are extended to Professor J. F. Read and to G. E. Fairbrothers who offered constructive criticism of the manuscript. Konrad Crist and Sue Bruce provided photographic help, and Gail Crum, Rita Sumas and Bernadine Harrell did the typing.

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MINERAL DEPENDENCY VERSUS MINERAL VULNERABILITY[1]

This is an audience, I know, that shares my interest in a subject that is currently getting a lot of attention — the tendency of our Nation to draw increasingly on overseas supplies of certain mineral commodities, and proportionately less on domestic sources for these minerals.

That we do obtain substantial quantities of some essential minerals from abroad is easy to demonstrate. That we will continue to do so in the foreseeable future is not in doubt. Uncertainty begins, however, when we try to interpret the significance of these facts. As with many phenomena, their meaning is open to a variety of interpretations.

The most commonly accepted interpretation is embodied in the phrase, "increasing mineral dependence." The word "dependence" has a negative connotation that is easy to grasp, and puts the trend into an uncomplicated perspective. "America's growing mineral dependence" has been the subject of articles and speeches in the minerals community for several years now, and shows signs of becoming a major policy issue of our day.

I propose today to question this interpretation of the statistics. Not to contradict it, no — the facts as I see them do not support a position as simple as that. But with responsibility for an agency whose primary concerns include discerning and interpreting mineral trends, to best promote the interests of our Nation, I feel obligated to point out that the bare concept of "America's increasing mineral dependence" is an over-simplification that leaves complex and important relationships unacknowledged — relationships that we must not lose sight of, if we wish to steer the most advantageous course for our Nation in the closing decades of the Twentieth Century.

Let me begin by tracing, to the best of my understanding, the origin of the phrase "increasing mineral dependence." The germ of this concept lay, of course, in the statistics that show America's mineral demands being met more and more by overseas sources. That trend has been underway for many years. Widespread interpretation of its true significance, however, was not attempted until the Arab oil embargo of 1973, and the subsequent OPEC price increases for petroleum. Overnight, America was shocked into the realization that self-sufficiency for a commodity of primary importance had vanished. It had not *vanished* overnight, of course; it had been leaking away for some years, and the trend was widely noted in government and industry. Widespread public appreciation of it did not come until the embargo, however, and the shock to our psyche was intense. In retrospect, it was even worse than the shock to our pocketbooks, which most of us have so far, somehow, managed to live with. But the dismay at finding out how vulnerable we were, not just to overseas shortages of a vital fuel but to overseas manipulation of supply — that dismay cut deeply, and the wound is a long way from healing. Our national self-esteem, our pride, has suffered a jolting blow.

Within the minerals community, the reaction to that revelation has been widespread, encompassing both the private and the public sectors. In part it has consisted of a search for suspected weaknesses in our resource posture — weaknesses that, if exploited by a foreign power, might expose us to the same kind of vulnerability we've experienced with respect to petroleum. Not surprisingly, evidence of some weaknesses has been found. America's heavy reliance on foreign sources for more than a score of minerals has been documented, and the case for the existence of "increasing mineral dependence" has been set forth.

I contend, however, that the case is not so simple as it has been made to appear. Dependence does not necessarily and inevitably lead to vulnerability. In the first place, petroleum is a special instance. No other mineral commodity combines the degree of universal indispensability and centralized foreign control of supplies that characterizes oil. Perhaps steel comes as close as any material to being universally necessary; we are fairly self-sufficient in iron ore, importing only about a fourth of our needs. Many of the other minerals that we require are produced by far fewer countries that export petroleum, but those minerals cannot approach petroleum in economic or industrial importance. It is hard to imagine a "bauxite embargo" or a "copper embargo" that could have anything like the impact of the oil embargo.

This puts an upper limit, therefore, on our understanding of the word "dependence" with respect to mineral resources. Whatever the situation may be, it has not yet demonstrably gone so far as vulnerability. So — how far *has* it gone?

---

[1]Remarks by Lindsay D. Norman, Director, U. S. Bureau of Mines at the 83rd National Western Mining Conference in Denver, Colorado, February, 1980.

Asking that question leads us to enquire into the mechanics of our "mineral dependency." What has happened, over the past 20 years or so, to shift America's supply base from domestic to foreign sources for some minerals? Is it a simple depletion of domestic reserves, a more complicated failure of foresight and policy, or an ominous international plot?

The beginnings of an answer lie, I believe, in the most obvious fact of the post-World-War-II international economy — prosperity. Since the devastation of that war was repaired, the world in general has enjoyed an unprecedented economic boom. This is reflected in the world production figures for almost any mineral you care to name — steel, cement, copper, aluminum, and so on and on. Prosperity brought with it a healthy international expansion of production of many commodities for which a single nation, or a small group of nations, had dominated the pre-war world. Under such circumstances, it is not surprising that domestic consumers would choose to avail themselves of that expanded market, and the economies competition brings, to meet their needs.

Obviously such a situation, as described, cannot be characterized as wholly undesirable. It is clearly to the advantage of our economy for industrial consumers to be able to pick and choose among international sources of supply. From the consumers' point of view, much flexibility has been gained, and any problems that may arise with domestic sources of supply can be by-passed by switching to overseas sources — and vice versa. For the world as a whole, the situation is healthy, too. Nations are brought together in the mutual self-interest of trading partnerships, and commercial competition has the opportunity to replace more destructive international relationships.

Yet there are voices warning us against the trends inherent in these developments. From another perspective, these trends are seen to comprise our "mineral dependency," so chillingly illustrated by the example of an oil situation. From this point of view, then, we see that "dependence" is being defined as any trend that can be likened to the petroleum situation — whether or not the *degree* of dependence is as severe as in the case of oil.

It is impossible to quarrel with the concern that animates this point of view. Without a doubt, we let the oil situation get out of hand — we allowed our supply base to shift overseas and become a pawn, as it were, of international politics. We would be foolish to expose ourselves to more perils of that kind —even though they may be potentially less devastating.

The Soviet Union is often held up as an example of a nation that has thoughtfully and deliberately chosen to protect itself against such contingencies. The Soviet Union is virtually independent of imported minerals, we are reminded, at a time when the United States increases its mineral imports. This is true. A close study of how the Russians do it, however, reveals the workings of a system we have firmly rejected in most aspects. As an example, they prefer to mine ores that, by any economic test, must be called sub-marginal, if the only alternative is to import.

However attractive the advantages of such policies may seem to us at times, it is clear that no industrial democracy could afford to pursue them. Our larger self-interest forbids it. The real question is, how do we pursue that self-interest in ways that minimize our risks amidst the uncertainties of the international market? To put it another way, how do we define the word "dependency" in terms of our mineral imports?

Let us begin by re-emphasizing the distinction between "dependency" and "vulnerability." We may be "dependent" on foreign sources for twenty-five percent of our iron ore, but are we vulnerable? Probably not. It seems to me that the problem is a lot more manageable in this light. It becomes clear, in fact, that by splitting "dependency" into two more workable concepts we have identified two points on a spectrum — a range of values encompassing varying degrees of self-sufficiency and dependency. Our proper objective, then, is to determine where on that spectrum we wish to be, with respect to any given mineral.

Who makes that determination? Who gets to say "hold chromium imports at the present level," for instance, or "reduce copper imports from this country and that"? Even more important, on what basis do such decisions get made?

The answer to the first question is obvious: the Government. If the trends generated by the operation of the international market are widely agreed to be undesirable, only the Government has the authority to make the necessary changes through such mechanisms as tariffs, quotas, tax credits, and so forth. But how does the Government determine what to do, and when?

That process always has involved and doubtless always will involve contributions from many different areas of expertise. But, there is in Government today a new awareness of the complexity of our mineral supply problems, and a new consciousness of the need for an enhanced mineral expertise in developing workable approaches to them. In fact, the Bureau of Mines has just reorganized itself around the concept of becoming the Federal Govern-

ment's central agency for mineral problem and mineral policy analysis. Long a major source of minerals research and statistics, we are logically extending our mandate to permit an informed analysis of mineral trends, and of the probable results of policy alternatives suggested for Federal implementation. I would like to spend my remaining few minutes in describing the Bureau's new role, and its impact on the "mineral dependency/-vulnerability" issue.

To begin with, the issue cannot be seriously studied without breaking it into its logical components — that is, we must examine the individual mineral commodities one by one. This goes further than merely collecting and publishing the statistics on each, and the Bureau's new Minerals Availability System, or MAS, is designed to be the next step forward. The system aims at assessing the worldwide availability of nonfuel minerals, and its foundation is an ever-enlarging computerized data bank containing information on the world's minerals, deposit by deposit.

Our newly published report, "Copper Availability — Domestic," will serve as an illustration of how MAS works. (Copper was selected as one of the first commodities for study, not because it represents a vulnerability prospect but because it exemplifies many of the problems with which our domestic mineral industries must contend.) From the computer we extracted grade, reserve, and other ore data on the 73 key domestic copper deposits — the major deposits, producing or not, that have demonstrated reserves or resources. Then, for each of the deposits, we developed a detailed estimate of the costs of mining and milling the ore.

Capital expenditures and operating costs were estimated for every step from exploration through the concentration process. This permitted a financial evaluation of each property, and the final product then emerged: a tonnage-price relationship showing how much domestic copper would be available over a range of prices at varying rates of return.

The value of such a study, in any informed analysis of America's copper postion, is apparent. The study makes it possible to give quantitative answers to "what-would-happen-if" questions, expressed in terms of price changes, and it can be a building block for further analysis. This is the kind of ground-breaking work that must and *will* be done to approach the "mineral dependency" issue on a firm footing of fact.

The next step in such an approach will be taken by our Analysis group, which will use the MAS copper study in the construction of "scenarios" for possible future developments. Only from such analyses can really clear definitions of "dependency" and "vulnerability" emerge. As you can see, many factors might enter into the definition, including the domestic reserve base for the mineral under consideration, the effect or price changes on that base, the domestic labor supply, the history of output in a given foreign country and the factors that influence it, the diversity of foreign sources, and so forth.

Such analysis is valuable not only for the additional insights it provides policymakers, but also for the help it gives to the Bureau's own planners in programming research. Through research we can try to change an important term of the "vulnerability equation" — the term that stands for current technology. And a better understanding of where dependency ends and vulnerability begins with respect to specific commodities enables us to allocate our research resources as efficiently as possible.

Extensive analysis isn't always needed, of course. We already know, for example, that domestic bauxite production is a fraction of domestic demand, and that one source accounts for half our imports. In such a situation, one can readily glimpse the *prospect* of vulnerability. And minimizing such prospects is an important objective of Bureau research.

Consequently, we have research underway that is exploring non-bauxite sources of alumina. Such sources are abundant, of course, but the technology for recovering them has not been economic. A few years ago, the Bureau evaluated the non-bauxitic sources, and the applicable extraction methods, and set up a "mini-plant" to test the most promising combinations. In the end, we identified a hydrochloric acid process, using clay for a raw material, as the best possibility, and plans for a pilot plant to test and refine the process have been drawn up. We don't anticipate, of course, that successful tests will eliminate bauxite imports and start a whole new American mining industry; such expectations would be unrealistic. Within the bounds of our dependency on foreign bauxite, however, we are entitled to a "fall-back position" — a domestic line of defense against potential interruptions of bauxite shipments, or unwarranted price increases; in short, a defense against vulnerability.

In a similar endeavor, the Bureau is working on a process that could make domestic supplies of cobalt, nickel, and chromium available from the lateritic ores of the Oregon-California border region. Although the potential addition to supply would offset only a small portion of current imports, the process does appear to have economic potential.

At this point it is appropriate, I think, to consider one of the issues that is uppermost in the industry's mind, whenever the subject of increasing imports

comes up. That issue is regulation, chiefly environmental and health and safety regulation. The increasing costs of regulation are said to be a significant factor in shifting supply from domestic to foreign sources. The Bureau of Mines has two concerns here. First, we want to develop the ability to show with some precision what the impact of new regulations would be on the mineral industry both in dollars and in output. Such precision, which no one has yet been able to achieve, should go a long way toward settling the often-fruitless debates over regulatory proposals. Second, the Bureau's environmental research program is aimed at providing a sound technological basis for new regulation. I don't think anyone would deny that, in some instances, intense and genuine concern over pollution and occupational hazards has led to the formulation of regulations that just couldn't be met with available technology. We are determined to minimize such occurrences in the future.

These are only a few examples of what the Bureau of Mines is doing. It is clear to me, however, that we are not doing enough. The job is so important, and has been so inadequately defined up to now, that much remains to be done.

First of all, the data analysis and policy evaluation function must be nurtured carefully to reach its full growth. We are building our capabilities deliberately, step by substantial step, to get a program that can stand on its own. We will be working to strengthen this program significantly in the years ahead. I believe it represents a really important extension of traditional Bureau efforts in mineral economics.

Next, the Bureau of Mines can and must do more in research. Our recent reorganization, aimed in part at streamlining the research effort, will greatly facilitate an expanded search for more domestic sources of important minerals that we import in large quantities. Of course, our research will become a more effective tool as it comes under the increasing guidance of our mineral analysis program, which will be able to "pinpoint" promising research targets with far greater accuracy.

The United States is a great country. We are even stronger and more resilient than we might have believed ourselves to be, ten years ago. We have absorbed the shock of an oil embargo, and subsequent price increases, but not without major inflationary impacts. To avoid additional ones, we must find intelligent ways to protect ourselves. And there is every reason to believe that intelligently conceived protective measures will succeed. All we really need, in my opinion, is the will to commit our resources to the work, and the self-confidence to keep us on the chosen course without faltering.

SUMMER CREDITED ENVIRONMENTAL EDUCATION COURSES

For the twenty-fifth year the Environmental Education Courses will be held at Virginia colleges. These three week summer courses in June and July are designed to acquaint teachers and others to become better acquainted with Virginia's mineral resources, wildlife, forests, soil and water and marine life.

Courses are offered for credit at Virginia Tech, William & Mary, Virginia State, and Longwood. Specialists from the various disciplines offer their time as instructors. Full and partial scholarships are given. By means of classroom discussion and field trips information is given which can assist in making decisions about resource and environmental management. Since these courses began some 2000 teachers and through them 250,000 students have been exposed to a better appreciation of natural resources. The scholarships are supported by contributions from industry, soil and water conservation districts, and various recreational clubs.

Information on scholarships can be obtained from: Virginia Resource Use Education Council, c/o Bernard L. Parsons, VPI & SU, Seitz Hall, Blacksburg, VA 24061. Those submitting applications early stand the best chance of getting scholarships at the institution of their choice.

SCHEDULED MEETINGS

February 22-27 American Society of Photogrammetry - American Congress on Surveying and Mapping at Washington Hilton Hotel, Washington, D. C.

March 19, 20 Southeastern Section, Geological Society of America in Hattiesburg, Mississippi (Daniel A. Sundeen, Dept. of Geology, University of Southern Mississippi, Box 8196, Southern Station, Hattiesburg, MS 39401).

April 9-11 Northeastern Section, Geological Society of America in Bangor, Maine (Arthur M. Hussey, Dept. of Geology, Bowdoin College, Brunswick, Maine 04011).

May 14, 15 Virginia Academy of Science (Geology Section) at Old Dominion University, Norfolk.

June 5-7 Eastern Section, National Association of Geology Teachers, in Brockport, N. Y. (Richard M. Liebe, Dept. Earth Sciences, SUNY, Brockport, N. Y. 14420).

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PUBLICATION 23

Geologic Structure and Hydrocarbon Potential along the Saltville and Pulaski Thrusts in Southwestern Virginia and Northeastern Tennessee by M. J. Bartholomew and others. This publication consists of six sheets which show rock character and deformation in parts of Montgomery County, Virginia and Hawkins County, Tennessee by means of interpretive cross-sections, photographs, geologic maps, and a road log. The locations of oil and gas fields in southwestern Virginia are shown. Information is listed for significant exploratory test and natural gas potential is discussed, $10.50*.

PUBLICATION 25

Geology of the Willis Mountain Quadrangle by John D. Marr, Jr. One 36 x 48 inch sheet in color with sections on economic geology by Palmer C. Sweet and Triassic Geology by Michael B. McCollum, $4.50*.

PUBLICATION 26

Geology of the Andersonville Quadrangle by John D. Marr, Jr. One 36 x 48 inch sheet in color with a section on economic geology by Palmer C. Sweet, $4.50*.

SPECIAL PUBLICATION

Directory of Geologists Employed in Virginia (exclusive of U. S. Geological Survey, Reston) by H. W. Webb, Jr., 22 p., 1980 - $1.50*.

Listings included are: geologists' names; organization addresses and geologists' job titles; and organization names. Both mailing addresses and phone numbers of place of employment are indicated.

*For publications mailed to Virginia addresses, add 4 percent State sales tax.

VIRGINIA MINERALS

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NATURAL GAS IN VIRGINIA

D. C. Le Van

Natural gas is produced in Buchanan, Dickenson, Russell, Tazewell, and Wise counties in the Appalachian Plateau of southwest Virginia, and in Rockingham County in the Valley and Ridge province. In addition, gas has been produced in Scott and Washington counties, also in the Valley and Ridge area. Production of gas during 1979, entirely from the Plateau, was approximately 8.5 billion cubic feet; estimated gas reserves as of 1979 (Virginia Department of Labor and Industry, 1980) were sufficient for 13 years at the 1979 rate of production. Virginia gas is produced for both the commercial market and local use. Gas from Buchanan, Dickenson, Rockingham, and Tazewell counties is marketed commercially to major pipelines in Kentucky and West Virginia. Smaller quantities of gas are produced in Russell and Wise counties for local in-state industrial use. The generalized distribution of oil and gas fields and geologic provinces in Virginia is shown in Figure 1.

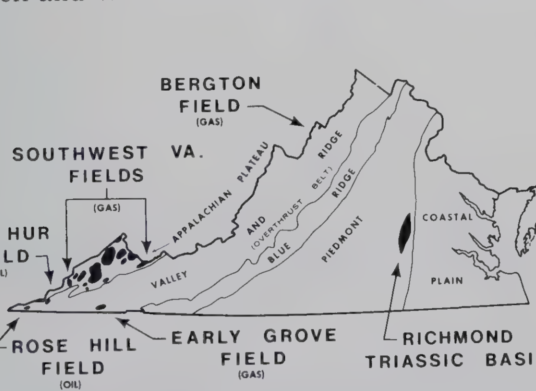

Figure 1. Generalized distribution of oil and gas fields and geologic provinces in Virginia.

A high level of interest exists among major petroleum companies and independent operators in the possibility for new gas discoveries in a large area that extends from New York southward through western Virginia to Alabama. This area is referred to by industry as the "eastern overthrust belt" because of geologic similarities to the "western overthrust belt" of the Rocky Mountains, where major discoveries of oil and gas are being made. Significant discoveries of natural gas have likewise recently been made in the eastern overthrust belt in West Virginia and Pennsylvania. The Appalachian Plateau and Valley and Ridge province of western Virginia are a part of this eastern overthrust belt. Industry has negotiated leases on much of the private and public land in western Virginia, from Lee County on the south to Frederick County on the north.

In western Virginia, production of natural gas has been developed over wide areas of the Appalachian Plateau province since 1948. Drilling of development wells and some exploratory tests continues to expand the known areas of commercial gas resources in the Plateau section. Presently known commercial occurrences of gas or oil in the Valley and Ridge province in Virginia are two gas fields, one of which is not now in production, and two small oil fields, all discovered during the period 1931-1963. Intensive exploration studies, including seismic work, are currently being done in this province

by industry and government. Current geologic concepts (e.g. Harris, Harris, and Epstein, 1978) suggest that the Valley and Ridge area is chiefly a potential natural-gas province and that conditions are less favorable for large-scale petroleum reserves. It is anticipated that a number of significant wildcat wells will be drilled within the next two years to explore this prospective area of the Commonwealth. Recent seismic work suggests that the sedimentary strata of the Valley and Ridge province may extend eastward beneath crystalline rocks of the Blue Ridge and Piedmont, thereby greatly enlarging the area of interest (Harris and Bayer, 1979).

REGIONAL EXPLORATION AND DEVELOPMENT

Appalachian Plateau Province

Most of the current production of natural gas in Virginia is from the Appalachian Plateau province, where approximately 500 wells have been drilled. Gas was discovered in Buchanan County in 1948, Dickenson County in 1949, Wise County in 1953, Russell County in 1955, Tazewell County in 1961, and northern Scott County in 1976. Pipeline delivery of gas from Buchanan County was begun in 1952, followed by Dickenson County in 1956 and Tazewell County in 1964.

During 1979 a total of 8,543,810,000 cubic feet of gas were produced by eight companies from 258 wells in the five currently productive Plateau counties (Virginia Department of Labor and Industry, 1980). Production has not been developed in the Plateau portions of Scott or Lee counties. During 1979 Dickenson County was the leading producer, followed in order by Buchanan and Tazewell counties. The 258 productive wells were distributed as follows: Buchanan 130; Dickenson 106; Russell 1; Tazewell 19; Wise 2. The leading producing company was Columbia Gas Transmission Corporation with 122 gas wells, followed by Philadelphia Oil Company with 68 wells, Ashland Exploration, Inc. with 36 wells, and 5 other companies with 13 or fewer wells (Virginia Department of Labor and Industry, 1980). Annual gas production from Buchanan, Dickenson, and Tazewell counties is shown graphically in Figures 2, 3, and 4.

The gas occurs principally in the Greenbrier Limestone ("Big Lime") and the Berea and other sandstones of Mississippian age, and in Devonian shale at depths that range from approximately 3500 to 6000 feet. The regional stratigraphy of gas-bearing Mississippian rocks in southwest Virginia and adjacent states has been described by Wilpolt and Marden (1959) and more recently by DeWitt, Cohee, and McGrew (1979) and Englund (1979).

Present drilling in the Plateau province is chiefly focused upon filling in and extending areas of present gas production in the formations that are now productive. The possibilities for production from older strata below presently developed zones remain to be evaluated by additional deep drilling in the area. The Devonian shale section is gas-bearing over a wide range of the Appalachian Basin, and, as

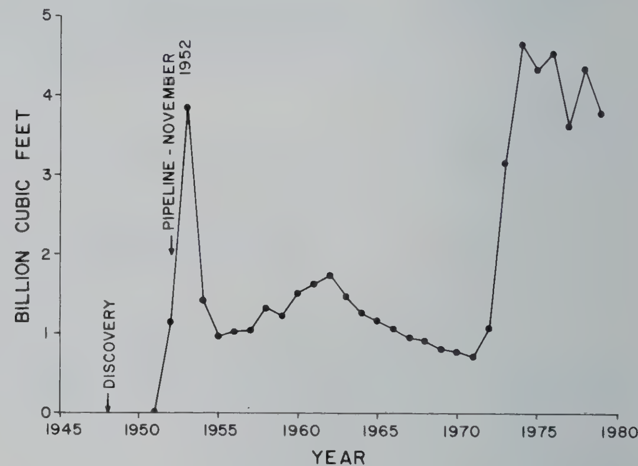

Figure 2. Annual gas production from Buchanan County. Data for 1955-79 from issues of Annual Report published by Virginia Department of Labor and Industry. Data for 1948-54 from unpublished information in Division files.

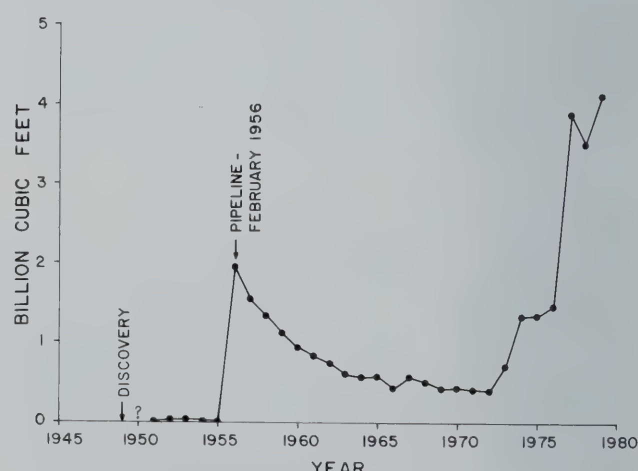

Figure 3. Annual gas production from Dickenson County. Data for 1955-79 from issues of Annual Report published by Virginia Department of Labor and Industry. Data for 1949-54 from unpublished information in Division files.

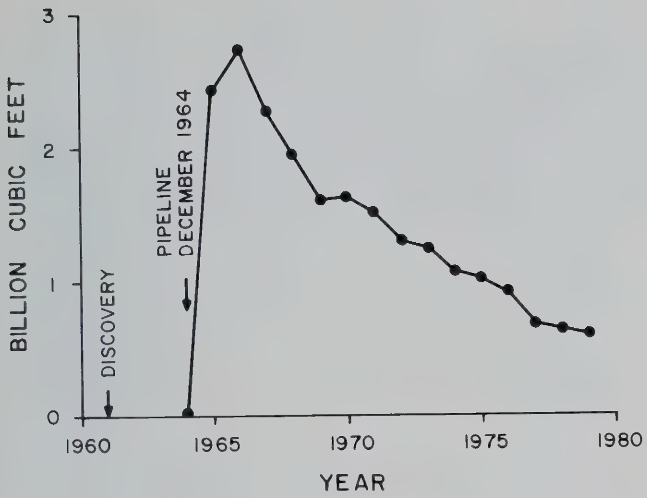

Figure 4. Annual gas production from Tazewell County. Data from issues of Annual Report published by Virginia Department of Labor and Industry.

noted, supplies some gas in the Plateau province of Virginia. The shale represents a large potential source of gas. Maximum utilization of this resource appears dependent upon development of appropriate techniques for siting wells in favorable fracture zones and for artificial stimulation of the gas yields into wells. Detailed studies have been made by numerous research groups as a part of the Eastern Gas Shales Program, sponsored by the U.S. Department of Energy, and by the petroleum industry. Methane associated with coal beds in the Plateau also constitutes a potential resource. Lack of appropriate technology and legal questions concerning ownership of the methane have hindered development of this possible source of gas.

VALLEY AND RIDGE PROVINCE

As a part of the exploratory effort in the eastern overthrust belt, major oil companies and independent operators are conducting extensive geological and geophysical work in the Virginia portion (an area of about 10,000 square miles) of the Valley and Ridge province. This area is underlain by strata of Cambrian to Mississippian age that have been complexly folded and are cut by major eastward-dipping thrust faults. Potential exploration targets in this province include anticlines, ramps, and other fault-associated structures, and stratigraphic traps. Gas has been produced commercially from two fields located by early exploration activity and gas shows have been encountered during drilling at other localities.

Early Grove Gas Field: The first commercial gas discovery in Virginia was made in 1931 in the Valley and Ridge province. The discovery well was drilled on the axis of the Early Grove anticline in Scott County. This test well found gas that was gauged at 1,750,000 cubic feet per day in sandy zones of the Little Valley Limestone of Mississippian age at depths between 3212 and 3272 feet. Additional wells were drilled on this structure in Scott and adjacent Washington counties and gas production was developed from this formation. Gas was also found in Devonian shale in this field and some gas was reportedly produced (Huddle, Jacobsen, and Williamson, 1956). Gas from the Early Grove field was supplied to the city of Bristol by a small-diameter pipeline from 1938 until about 1958 when the field was abandoned. Annual production from the field is shown in Figure 5. The cumulative

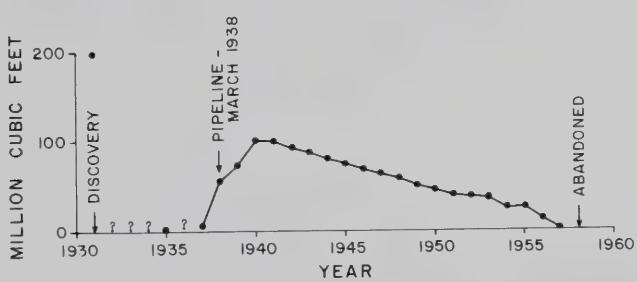

Figure 5. Annual gas production from the Early Grove gas field. Data for 1955-58 from issues of Annual Report published by Virginia Department of Labor and Industry. Data for 1941-54 from unpublished information in Division files; 1931-40 from Averitt (1941).

yield of gas to 1958, as totalled from various sources, is believed to have been about 1.3 billion cubic feet. A deep test drilled near the discovery well in 1963-64 encountered gas in the Clinch Sandstone (Silurian), which was measured at the rate of 103,000 cubic feet per day; the hole was plugged back and completed as a shut-in gas well in the Little Valley Limestone. A well drilled in this field in early 1980 reportedly found natural gas in the Price Formation of Mississippian age. Additional wells have been drilled during 1980 in an attempt to re-establish production from the field.

A wildcat well drilled in 1915 about two miles northeast of the present Early Grove field encountered a small pocket of gas which caught fire and burned the rig (Averitt, 1941). No further information is available for this well, which was drilled to a depth of approximately 2500 feet.

The geology and early development of the Early Grove field were described by Averitt (1941) who reported analyses of the gas as follows:

Sample from discovery well

methane	97.89 percent
ethane	1.57 percent
butane	.14 percent
pentane	—
propane	—
nitrogen	.40 percent
carbon dioxide	0.00 percent
oxygen	0.00 percent
moisture	none

Composite sample from all wells

Btu at 760 mm and 60°F	1028.5
S.G. at 760 mm and 60°F (air = 1)	.563

Bergton Gas Field: In the Valley and Ridge province, gas has also been found in northern Rockingham County on the Bergton-Crab Run anticline. The gas occurs here in the Ridgeley (Oriskany) Sandstone of Devonian age. Drilling began in the Bergton area in the 1930's and between 1951 and 1956 five gas wells were completed at depths of about 2985 to 3800 feet. Although some gas was used for local purposes, commercial production was not established until 1980 when a small-diameter pipeline was built by James F. Scott Oil and Gas to deliver gas from two of the wells to a major transmission line in West Virginia. New wells drilled in the Bergton field in 1980 have found additional gas and a second local line has been built by Merrill Natural Resources, Inc., to connect with the West Virginia pipeline. The geology and early exploration in the Bergton area were described by Young and Harnsberger (1955) who cite two analyses of the gas as follows:

A

methane	98.69 percent
ethane	0.12 percent
propane	0.01 percent
nitrogen	1.18 percent
carbon dioxide	0.00 percent
Thv. Btu/cu ft. Sat. 30 ins. Hg, 60°F	987
S.G. (air = 1)	0.5604

B

methane	97.1 percent
ethane	1.3 percent
propane	—
nitrogen	1.1 percent
carbon dioxide	0.3 percent
oxygen	0.2 percent
Thv. in Btu/cu ft.	997

Other Areas: Natural gas has been encountered during drilling at other localities in the Valley and Ridge area. In Lee County, Miller and Fuller (1954) report that a well drilled about two miles west of the Rose Hill oil field hit a flow of 225,000 cubic feet per day in the basal sandstone of the Cayuga dolomite (Silurian), and cite an analysis of the gas as follows:

methane	89.2 percent
nitrogen	2.7 percent
ethane	5.1 percent
propane	1.8 percent
butane	0.8 percent
Btu (saturated with water)	1024
Btu (dry)	1042

Another well in Lee County, about six miles northeast of the Rose Hill field, was reported (Miller and Brosgé, 1954) to have encountered a flow of gas from the Reedsville Shale (Ordovican) estimated at 100,000 cubic feet per day. Shows of gas were encountered in Ordovician and Cambrian rocks in a deep test drilled about a mile southeast of the Rose Hill field (Harris, 1967). In the Ben Hur oil field, also in Lee County, a well drilled in 1967 encountered a blowout of gas which caught fire while drilling was in progress in the Trenton Limestone (Ordovician). The gas flow into the hole was followed by oil and the well was subsequently completed as an oil well. Other gas occurrences reported by operators include an estimated flow of 50,000 cubic feet per day from the Martinsburg Formation (Ordovician) in Montgomery County and "less than 100,000" cubic feet per day after treatment of Ordovician rocks in a well in Russell County. Devonian shales that are widespread in the Valley and Ridge province have potential as sources of unconventional natural gas, as noted in the discussion of the Appalachian Plateau. Methane that may be associated with coal beds in the Valley coal fields is also a possible energy resource.

Recent evolution of geologic thought concerning the Valley and Ridge province is providing a better understanding of the potential for oil and gas. The geologic structure and hydrocarbon potential along major thrust faults in southwestern Virginia have been discussed in a recent publication of the Division of Mineral Resources (Bartholomew and others, 1980). The relationship of regional structure to areas of oil and gas production has been described by Harris and Milici (1977) and Milici (1980). Rader and Perry (1976) and Perry, Harris, and Harris (1979) present re-interpretations of geologic structures in the Valley and Ridge area and discuss the implications for hydrocarbon occurrence.

Blue Ridge and Piedmont Provinces

The Precambrian and Paleozoic crystalline rocks of the Blue Ridge and Piedmont are not appropriate environments for occurrences of oil and gas, and industry has traditionally regarded such areas as having no potential. Recent seismic and geologic data from various parts of the Appalachian area are interpreted by some (e.g. Harris and Bayer, 1979) to indicate that some Blue Ridge and Piedmont rocks may have been thrust westward for a distance of at least 100 miles and that sedimentary strata continuous with those of the Valley and Ridge province may be present at depths of 5,000 to 10,000 feet beneath them. A press release issued by the U.S. Geological Survey in October 1979 suggested that this concept may double the area of interest for natural-gas exploration in the Appalachian Mountains from Virginia to Alabama. Predictions concerning the nature of the inferred sequence of buried sedimentary strata have been made by Dennison (1980). Debate exists among various researchers as to whether gas or oil may have formed or been preserved in these strata. If suitable economic incentives and exploration techniques are developed, test wells may be drilled in Virginia to evaluate the potential of these postulated deep strata.

Approximately 15 wells are known to have been drilled in sedimentary rocks of the Richmond, Culpeper, and Farmville Triassic basins in the Piedmont. Shows of oil were reported in some of these tests, most of which were drilled during the period 1910-1945, but their validity is unknown as no further information is available. There is current interest by several groups in the possibility of producing the methane that may be associated with coal beds in the Richmond Basin, and some leasing and test drilling has been done in that area.

Coastal Plain Province and Continental Shelf

A few oil and gas tests have been drilled on the Coastal Plain in Virginia but no significant shows were encountered. Federal leases have been issued in several areas on the Outer Continental Shelf off the Mid-Atlantic states as a result of OCS Sale Number 40 in August 1976 and Sale Number 49 in February 1979. Gas-bearing zones and some oil have been found in wells drilled on OCS leases off New Jersey in the Baltimore Canyon trough, which approximately parallels the coast from New York to North Carolina. Further drilling is being done to evaluate the feasibility of commercial production in that area. The potential for hydrocarbon resources in the Baltimore Canyon trough has been discussed by Benson (1979). A discussion of the stratigraphy and depositional environments in the trough was presented by Poag (1979).

No drilling has taken place in waters off the Virginia coast where one tract, about 70 miles east of the Eastern Shore Pennisula, is under lease. A third sale of Federal offshore leases in the Mid-Atlantic area, Sale Number 59, is tentatively scheduled for December 1981. Tracts proposed for leasing in Sale 59 extend farther south and seaward than those leased in Sales 40 and 49 and include acreage off Virginia.

STATE NATURAL-GAS PRODUCTION

State production of natural gas for the years 1931-79 and drilling activity for the years 1955-79 are shown graphically in Figures 6 and 7. Virginia gas production for the years 1931-51, as shown in Figure 6, represents the limited output of the Early

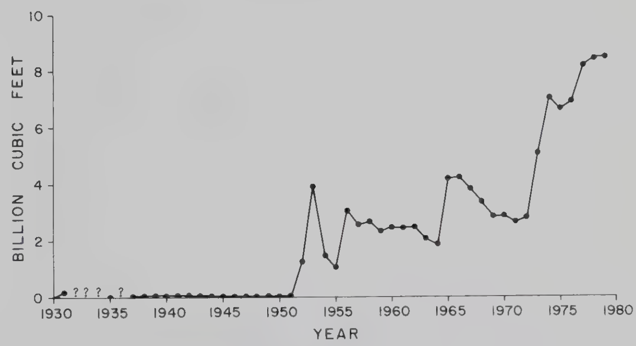

Figure 6. Virginia gas production for the years 1931-79. Data for 1955-79 from issues of Annual Report published by Virginia Department of Labor and Industry; 1931-54 from unpublished information in Division files.

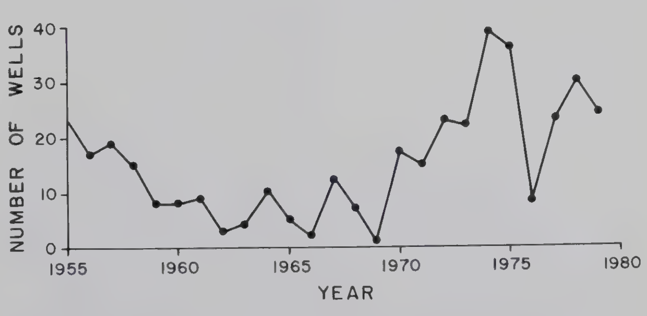

Figure 7. Drilling activity in Virginia for the years 1955-79. Data from issues of Annual Report of Virginia Department of Labor and Industry.

Grove field in Scott and Washington counties, following discovery in 1931. The large increase in State production commencing in 1952 coincides with the establishment of pipeline deliveries of gas from the Appalachian Plateau area of southwestern Virginia, where initial discovery was made in 1948, to a transmission line in West Virginia. The increased production for 1973 and subsequent years reflects a renewal of drilling effort in the Plateau area beginning in 1970, as shown in Figure 7, and the establishment of more-extensive, local gathering facilities. In 1979 there were 24 new test wells drilled in the State for oil and gas, of which 15 were completed as gas wells (Virginia Dept. of Labor and Industry, 1980). Total State remaining reserves of natural gas as of December 31, 1979 are reported by the State Oil and Gas Inspector (Fulmer, 1980) to be 111,027,374,000 cubic feet.

LEASING

A highly competitive leasing effort has been carried on in the Commonwealth by major companies and independents during recent years. A comparison of productive and nonproductive acreage under lease for oil and gas in Virginia and nearby states, as of January 1, 1979, is shown in Table 1. At that time about 1,205,866 acres, or 4.7 percent of the land area of the State, were under lease in Virginia. By the end of 1979 a total of 2,023,745 acres had been leased, and by September 1980 the total leased acreage had increased to between 2,750,000 and 3,000,000 acres, about 11 percent of the State, as reported by the State Oil and Gas Inspector. This leasing activity has been concentrated in the area west of the Blue Ridge and extends the length of the State from Frederick County to Lee County. Some leasing has recently taken place in the Blue Ridge and westernmost Piedmont areas of central Virginia; this activity is apparently based on the postulated eastward extension of sedimentary Valley and Ridge strata beneath the crystalline rocks of the Blue Ridge. Leases have also been acquired in the Richmond Triassic Basin of the Piedmont, chiefly for the methane resources that may be present in coal beds in the area.

Table 1. Estimated productive and nonproductive acreage under lease for oil and gas as of January 1, 1979 (from *Petroleum Information Package*, July 1, 1980, Exxon Company, U.S.A., p. 56).

	Total Land Area of State (Acres)	Total Land under Lease (Acres)	Percent of Total Land under Lease (Acres)
Virginia	25,459,200	1,205,866	4.7
Kentucky	25,376,000	3,925,000	15.5
Maryland	6,330,240	285,900	4.5
Pennsylvania	28,778,240	16,133,360	56.1
Tennessee	26,449,920	3,333,335	12.6
West Virginia	15,404,800	12,972,000	84.2

Both private and Federal lands have been leased extensively. There is no requirement for a standard lease form on privately-owned land in Virginia. Such oil and gas leases are subject to negotiation between the landowner and the company seeking to lease the land. Typical leases now current in western Virginia may provide, for example, for a bonus of from one to five dollars or more per acre upon execution of the lease, annual rentals of one dollar per acre, a royalty on one-eighth to the landowner from any production that may be established, and a term of five to ten years.

Applications for oil and gas leases in the George Washington National Forest totalled approximately 561,000 acres and in the Jefferson National Forest 455,000 acres as of May 1980. Leases in the National Forests are issued initially on a first-applicant basis by the Federal Government for a ten-year term unless dropped sooner or held by production. The leases carry annual rentals of one dollar per acre and provide for a one-eighth royalty to the Federal Government.

The petroleum industry has also expressed interest in leasing State-owned lands in Virginia. Tracts owned by the State are administered by various agencies and include such diverse categories as State Forests, State Parks, lands of the Commission of Game and Inland Fisheries, university lands, and submerged lands. A variety of mineral-right reservations and deed restrictions exist on some of these lands. There is no uniform policy regarding oil and gas exploration and leasing on State lands and the subject is currently undergoing review.

PRICE OF NATURAL GAS

The average wellhead value of natural gas produced in Virginia during 1979 was reported to be $1.68 per thousand cubic feet (Virginia Dept. of Labor and Industry, 1980). Wellhead values for natural gas in Virginia for the years 1947-1979 are shown in Figure 8. The rapid price increase that began in the mid - 1970's, together with the evolution of geologic concepts and the potential for an energy crisis, are providing new incentive for exploration for natural gas in Virginia.

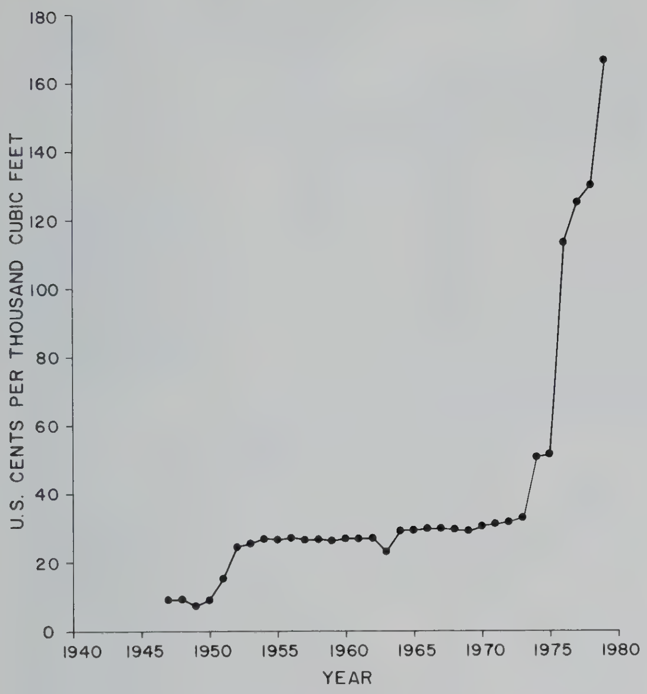

Figure 8. Average annual wellhead prices of Virginia natural gas 1947-79. Information for 1947-78 from American Petroleum Institute (1977 and update) and for 1979 from Virginia Department of Labor and Industry (1980).

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STAFF CHANGES

William F. Giannini of Scottsville, Virginia joined the permanent staff of the Division of Mineral Resources on August 1, 1980. Mr. Giannini, who received his M.S. in geology from the University of Virginia in 1959, was employed previously by the Flintkote Company at Stephens City, Virginia. He is in the Economic Section of the Division and is currently conducting a State-wide carbonate study. He is married and has a daughter.

Joseph J. Arnold of Hershey, Pennsylvania joined the permanent staff at the Division on August 18, 1980. Mr. Arnold received a B.S. degree in geology from the University of Miami in 1957 and a M.S. degree in geology from the University of Arkansas in 1960. His work experience includes nearly 20 years of employment in private industry and state government. Mr. Arnold is in the Economic Section where he is working on oil and gas, industrial minerals, metallics, and coal resources.

NEW EDUCATIONAL SECTION

Have you been reading "Outdoor Classroom" in the school issues of *Virginia Wildlife* magazine? The new section is especially designed for teachers and students. Included are articles about animals, insects, birds, fish, plants, the ocean, teaching aids, activities, interesting places in Virginia, and of course, geology!

All schools in Virginia should be receiving special copies of the Virginia Commission of Game and Inalnd Fisheries' monthly magazine during the school year. If your school is not getting its copy, please contact Mr. Harry Gillam, Editor, *Virginia Wildlife*, Virginia Commission of Game and Inland Fisheries, Box 11104, Richmond, Virginia 23230.

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BLUE QUARTZ IN VIRGINIA

Michael A. Wise[1]

In 1885, Robert Robertson described a peculiar variety of quartz from Nelson County, Virginia. This new variety of quartz, as cited by Robertson, "...presents a characteristic waxy luster and a color varying from pale to deep blue. It therefore appears of interest to ascertain to what this color is due." The color is now thought to be due to either minute rutile inclusions or to fractures.

The occurrence of blue quartz has been reported worldwide. Iddings (1904) noted blue quartz in a gray granite porphyry in Llano, Texas. Jayaraman (1939) found blue quartz pebbles occurring in the charnockites and gneisses of the Mysore Province in South India, and Goldschmidt (1954) cited the occurrence of small blue quartz pebbles in the metasedimentary rocks of Norway. In the United States, the mineral has been reported from Rhode Island to South Carolina.

Most blue quartz in Virginia is in the Blue Ridge Complex lying east of the Blue Ridge Mountains. The complex extends from Loudoun County in the north to Grayson County in the south. A few occurrences of blue quartz have been reported from the Virginia Piedmont.

The stratigraphic succession of the Blue Ridge Complex includes several rock units consisting of quartz-oligoclase-biotite gneiss, spilitic greenstone, metatuff, quartzites, dolomites and metamorphosed graywackes, arkoses and subgraywackes (Bloomer and Werner, 1955). These units, which range in age from Precambrian to Cambrian, overlie Precambrian gneiss and granite. The Blue Ridge Complex forms the core of the Blue Ridge anticlinorium. Most of the blue quartz in Virginia is from metamorphosed magmatic rocks of the Blue Ridge Complex (Figures 1 and 2). Figure 3 shows areas and collecting localities of blue quartz.

Figure 1. Old Rag granite at Old Rag Mountain. Gray grains are blue quartz.

[1]William W. Whitlock assisted with the field work for this article.

Figure 2. Blue quartz xenolith in the Old Rag granite at Syria.

MINERALOGY

The blue quartz found in Virginia exhibits most of the physical properties of colorless quartz. It has a hardness of 7, displays conchoidal fracture, a white streak and it is infusible before the blowpipe. When heated it retains its color, unlike some smoky or amethystine varieties. The specific gravity of blue quartz is 2.65 or higher depending on the kind and amount of included material. Inclusion-free blue quartz tends to have a lower specific gravity than specimens containing inclusions.

The uniqueness of blue quartz is due to properties that are uncharacteristic in ordinary quartz, opalescence, chatoyancy, and asterism. In addition, all blue quartz specimens are highly fractured and contain inclusions of rutile or other minerals.

OPALESCENCE AND CHATOYANCY

A striking characteristic of blue quartz is its opalescent, or waxy, luster. This waxy to greasy appearance is seen in all blue quartz. Light blue specimens tend to be more opalescent than darker specimens.

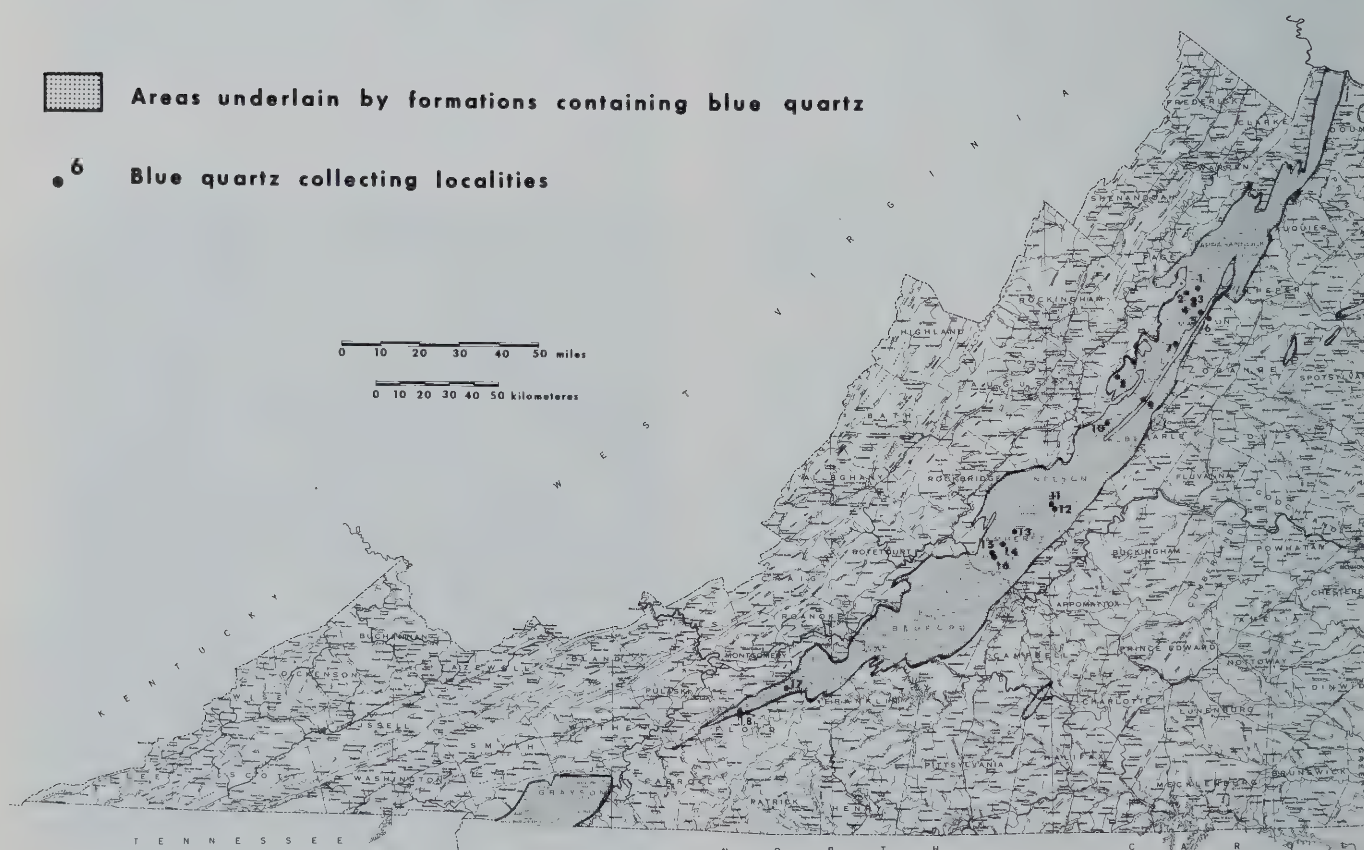

Figure 3. Reported blue quartz localities.

Chatoyancy, or changeable waxy luster, has been noted in some specimens of blue quartz. Pebbles along Byrd Creek in Goochland County show excellent chatoyancy (Dietrich, 1970).

ASTERISM

Asterism, the illusion of a star-like figure within certain minerals, has been known to occur in several blue quartz specimens. This phenomena is only observed in specimens artificially shaped into a sphere or a hemisphere and viewed in reflected light. Most specimens which show asterism display a 6-rayed star, but specimens from Bull Knob in Henry County exhibit a 4-rayed star (Dietrick, 1970).

INCLUSIONS

The majority of the blue quartz specimens of the world contain inclusions of rutile, TiO_2, but other minerals also exist as inclusions in blue quartz. These include microscopic needles of tourmaline (Parker, 1962), magnetite (Goldschmidt, 1954), apatite and ilmenite (Iddings, 1904) and zoisite (Dietrich, 1971). Rutile needles are the primary mineral inclusion in the Virginia specimens.

THE ORIGIN OF COLOR IN BLUE QUARTZ

The most noticeable property of blue quartz is its color, which ranges from light sky blue to dark grayish blue. The blue color has been attributed to three basic causes: the partial reflection of light from inclusions, the scattering of light by closely spaced microfractures in the quartz, and the occurrence of scattered titanium as a coloring agent. Each of these factors can produce a blue color in quartz.

Color Due To Inclusions: Closely spaced, colloid-size inclusions of acicular or tabular crystals occur in many blue quartz crystals. The size of the inclusions ranges from 0.02 to 1 micron in thickness and from 1 to 500 microns in length. These tiny inclusions selectively scatter visible light of the shorter, or blue, wavelengths (about 480 millimicrons), thus giving a blue color to the quartz. The amount of scattering seems to be a function of the smallest dimension of the inclusions and of the difference between the mean index of refraction of the included material and of the quartz. The particle size producing maximum scattering of light would be 0.2 to 0.5 microns in diameter (Jayaraman, 1939).

Figure 4. Photomicrograph of blue quartz with inclusions of rutile needles. Note the preferred orientation of the needles. Crossed nicols, 100X.

Photomicrographs have shown that most of the inclusions are slightly oriented (Fig. 4). Antler-shaped zoisite crystals tend to occur in a roughly radiating pattern (Dietrich, 1971). Tourmaline (Parker, 1962) and rutile (Ross, 1941) crystals occur as sets of parallel needles intersecting one another and lying in the basal plane (0001) of the quartz. These preferred orientations are thought to be controlled by the trigonal symmetry of the quartz (Ross, 1941).

Color Due To Fractures: The numerous microfractures throughout blue quartz is another probable cause of the blue color. Generally, the fractures are closely spaced and subparallel to one another. Evidence supporting fractures as a cause of the blue color is given by the fact that some inclusion-free samples of blue quartz are blue and that some specimens lose their blue color upon granulation. Dietrich (1971) examined specimens of inclusion-free blue quartz and found that they were highly fractured and strained; in some cases the degree of fracturing was correlated to the depth of the blue color.

Color Due To Titanium: Finely divided rutile is blue as is ilmenite which contains titanium, and inclusions of these minerals in quartz could produce a blue color. However, some specimens of blue quartz contain no titanium. Conversely, some specimens of quartz with substantial titanium are rose and some are clear.

COLLECTING LOCALITIES FOR BLUE QUARTZ

Madison County:

1. From Madison proceed north on State Highway 231 to State Road 643 (approximately 10 miles). Turn left on State Road 643, proceed for 0.6 miles to State Road 645. Turn right on State Road 645, proceed for 1 mile. Blue quartz is in stream gravels of Ragged Run.
2. From Madison proceed north on State Highway 231 to Banco. Turn left on State Road 670 and continue to Syria. Turn right on State Road 600 and proceed for approximately 2.7 miles. Blue quartz is in Old Rag granite on the right.
3. From Madison proceed north on State Highway 231 to Syria. Turn right on State Road 600 and proceed for approximately 0.8 miles (just past the church). Blue quartz is in a large vein on the right.
4. From Madison proceed north on State Highway 231 to Criglersville on State Road 670. Stream gravels along the Robinson River between Criglersville and Syria contain some blue quartz.
5. From Madison proceed north on State Highway 231 to Banco. Blue quartz is in the stream gravels of the Robinson River.
6. From Madison proceed north on State Highway 231 for approximately 0.6 miles to State Road 638. Turn right on State Road 638 and proceed to the bridge crossing the Robertson River (approximately 1.5 miles). Blue quartz is in the stream gravels.

Greene County:

7. From Stanardsville proceed north on State Highway 230 to the county line. Blue quartz is in the stream gravels of the Middle River.

Albemarle County:

8. From Charlottesville, proceed west on State Road 654. Continue west on State Road 601 to State Road 614. Continue west on State Road 614 to Whitehall. Turn right on State Road 810 and continue to Browns Cove. Turn left on State Road 629 to end of the road. Blue quartz is in small veins in country rock.
9. From Charlottesville proceed west on State Road 654. Continue west, then north on State Road 601. Blue quartz is in a roadcut on State Road 601 between the bridges over the Mechums and Moormans rivers.
10. From Charlottesville proceed west on U.S. Highway 250. Turn left on State Road 824 and continue to the bridge over Stockton Fork. Blue quartz is in a gneiss exposed in stream banks.

Nelson County:

11. From Lovingston proceed southwest on State Highway 56 to State Highway 151. Proceed north on State Highway 151 to its intersection with State Highway 56. Park at the bridge. On the north side of the Tye River approximately 750 yds. from the road blue quartz occurs as stringers and veins in a gneiss.
12. From Lovingston proceed southwest on State Highway 56 to State Highway 151. Proceed north on State Highway 151 to its intersection with State Road 655 (just across the Tye River). Turn right on State Road 655 and continue for approximately 1 mile. Blue quartz is in the roadcut near the intersection of State Road 655 and 724.

Amherst County:

13. From Amherst, proceed west on U.S. Highway 60 and State Road 610. Turn left on State Road 610 and proceed for 0.3 miles to the bridge over the Buffalo River. Blue quartz is in the stream gravels.
14. From Amherst proceed west on U.S. Highway 60 to State Road 610. Turn left on State Road 610 and proceed for approximately 5.5 miles. Blue quartz is in a roadcut on the right.
15. From Amherst proceed west on U.S. Highway 60 to State Road 610. Turn left on State Road 610 and continue to State Road 635. Turn left on State Road 635 to Pedlar Mills and State Road 643. Turn right on State Road 643 and travel to the end of the road. Blue quartz is in the stream gravels of the Pedlar River.
16. From Amherst proceed to Pedlar Mills. Blue quartz is in the stream gravels of the Pedlar River.

Floyd County:

17. From Floyd, proceed northeast on U.S. Highway 221 to State Road 661. Turn left on State Road 661 to State Road 610. Continue east for 0.1 miles then turn left on State Road 653. Continue for approximately 4 miles past the Hemlock Church to the bridge where Goose Creek crosses State Road 653. Blue quartz is in the stream gravels.
18. From Floyd, proceed north on State Highway 8 for approximately 10 miles. Blue quartz is in the stream gravels of Little Camp Creek.

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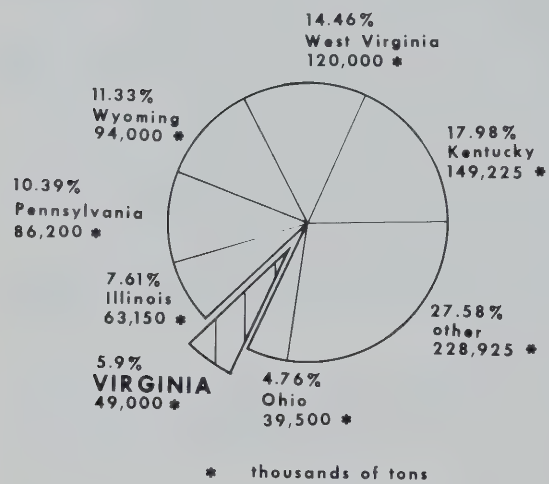
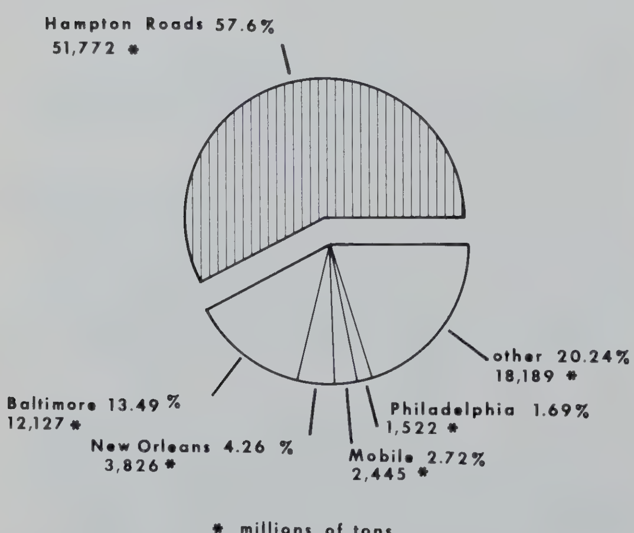
MINERAL ACTIVITY

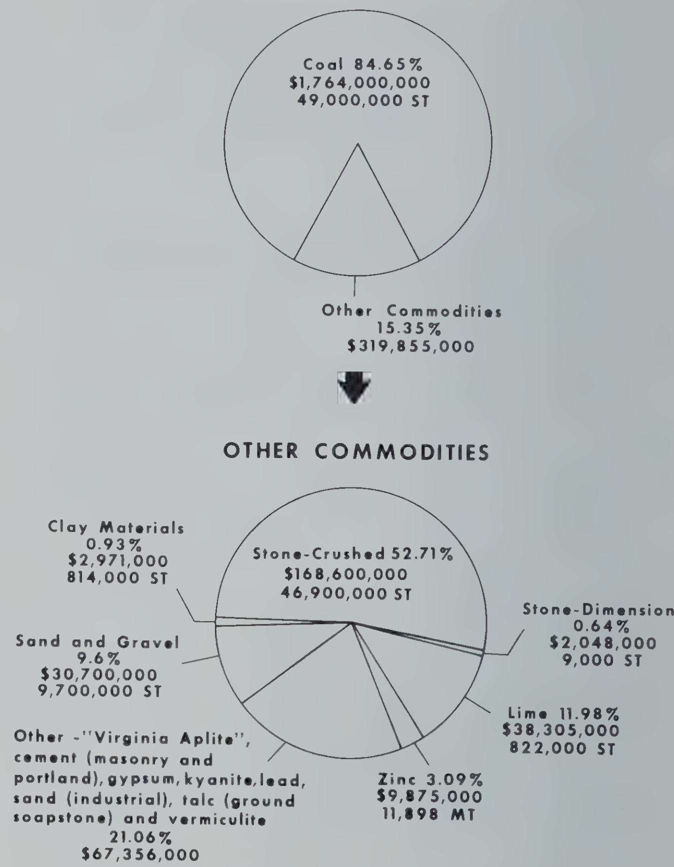
⚒ Virginia coal production for 1981 as of March 28 was 12,955,000 tons. In 1980, 49 million tons of coal (U.S. Department of Energy) were produced in Virginia; an increase of 32.3 percent over 1979 production, which was 37,038,000 tons. Virginia ranked 6th among States in 1980 coal production. In 1980, more coal was exported at Hampton Roads than at any other port. See figures below for details.



U.S. coal production by state for 1980.



U.S. coal exports for 1980.



Virginia mineral production for 1980.
(excludes petroleum and natural gas)

⚒ Nonfuel mineral production in Virginia for 1980 was more than 3 percent higher in value than in 1979. Quantities of clay materials, lime, sand and gravel, and crushed stone produced in 1980 were all less than in 1979.

⚒ Marline Uranium Corporation is exploring for uranium resources in Pittsylvania County in the southern Virginia Piedmont as well as in Culpeper, Madison, Orange, and Fauquier counties of the northern Virginia Piedmont. Several forums have been held in the northern Piedmont area to address the questions and concerns of the community.

⚒ Production of diatomaceous sediments for use as an absorbent material is being planned for sites in King and Queen County. A plant to dry the material is planned to open in early 1982; it will utilize wood as a fuel.

MINERAL RESOURCES IN BUCKINGHAM COUNTY

Important mineral resources for a part of Buckingham County, central Virginia, are described in a new publication. The 83-page publication is composed of five separate articles about the type of rocks and mineral resources there. A road log of where to see significant features and six geologic and geophysical maps are included. These maps show the distribution of rock types and of significant sulfide zones. Aeromagnetic, aeroradiometric, gravity, and geochemical characteristics, useful in locating mineral resources, are illustrated. Sulfide zones with zinc, copper, and silver are indicated from geochemical studies. The locality of the leading producer of kyanite in North America is in this area. Other resources described are feldspar, mica, coal, copper and manganese. The mineral resources investigation was funded in cooperation with the Piedmont Planning District Commission, Farmville, Va. and the U.S. Coastal Plains Regional Commission. Publication 29 is entitled "Geologic Investigations in the Willis Mountain and Andersonville Quadrangles, Virginia." It can be obtained by mail for $8.50 from the Division of Mineral Resources, Box 3667, Charlottesville, Va. 22903. A free List of Publications of other publications and topographic maps is available upon request.

GREAT DISMAL SWAMP MAPS

An innovative map-picture of the Great Dismal Swamp in southeastern Virginia is now available. Some 350 square miles, extending from metropolitan Suffolk and the Town of Great Bridge southward approximately three miles into North Carolina, are shown on six adjoining multicolor orthophotomaps. The six orthophotomaps arranged together measure about 5 feet by 4 feet. Orthophotomaps are basically aerial photographs to which colors and symbols have been added to identify features shown. These maps which were developed by the U.S. Geological Survey in cooperation with the Division of Mineral Resources of the Virginia Department of Conservation and Economic Development, are an example of the latest map-making techniques.

Lake Drummond appears as a prominent blue feature surrounded by green swamp and trees on the maps. Because the aerial photograph was taken in the Springtime, when deciduous trees had no leaves, the shades of green on the map can be used to interpret various types of vegetation. The configuration and slope of the land surface can be interpreted from numbered contour lines. Cultural features include houses, maintained roads, drainage ditches and canals, and railroads. Distances between points of interest can be determined from the map scale. All six orthophotomaps can be obtained for $7.80, or the separate maps for $1.30 each, from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, Va. 22903. An index to map coverage is available upon request.

ROCK AND MINERAL SETS

Twenty of Virginia's common rocks and minerals are available packaged in a 1½ × 9 × 11 inch box. Each numbered specimen is described and placed in individual trays. The set is available from the Division for $3.12 (add $2.50 for postage to Virginia addresses and $3.00 to addresses outside of Virginia).

SUMMER CREDITED ENVIRONMENTAL EDUCATION COURSES

For the twenty-fifth year the Environmental Education Course will be held at Virginia colleges. This three week summer course in June and July is designed to acquaint teachers and others with Virginia's mineral resources, wildlife, forests, soil and water and marine life.

Courses are offered for credit at Virginia Tech, William & Mary, Virginia State, and Longwood. Specialists from the various disciplines offer their time as instructors. Full and partial scholarships are given. By means of classroom discussion and field trips information is given which can assist in making decisions about resource and environmental management. Since these courses began some 2000 teachers and through them 250,000 students have been exposed to a better appreciation of natural resources. The scholarships are supported by contributions from industry, soil and water conservation districts, and various recreational clubs.

Information on scholarships can be obtained from: Virginia Resource Use Education Council, c/o Bernard L. Parsons, VPI & SU, Seitz Hall, Blacksburg, VA 24061. Those submitting applications early stand the best chance of getting scholarships at the institution of their choice.

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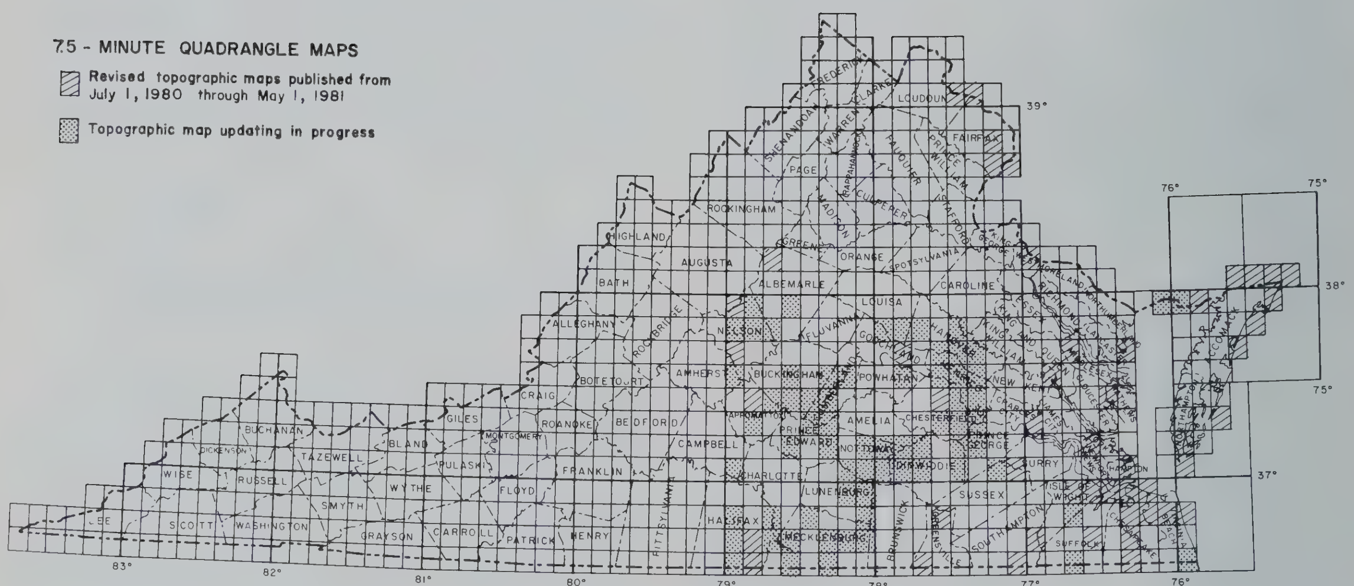

Revised 7.5 minute quadrangle maps published from July 1, 1980 through May 1, 1981:

Annandale
Barley
Benns Church
Boxiron
Brandon
Browns Cove
Chrisfield
Church View
Colonial Beach South
Deep Creek
Fishermans Island
Fleets Bay
Fort Belvoir
Franklin
Girdle Tree
Great Machipongo Inlet
Hampton
Kempsville
Lake Drummond SW
Little Creek
Metomkin Inlet
Newport News South
Omega
Pocomoke City
Princess Anne
Purdy
Seneca
Smithfield
Sterling
Suffolk
Sunbeam
Townsend
Virginia Beach
Wallops Island
Ware Neck
Whittington Point
Yorktown

VIRGINIA MINERALS

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
Richmond, Virginia

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FIELD GUIDE TO SELECTED PALEOZOIC ROCKS, VALLEY—RIDGE PROVINCE, VIRGINIA

PART I: ROANOKE, CLIFTON FORGE, FRONT ROYAL AREAS

Thomas M. Gathright, II and Eugene K. Rader

This field trip is designed to show some of the exposed potential reservoir beds of Silurian age, structural style west of the mid-province front, Middle and Upper Ordovician turbidite sequences, and structural style of the Blue Ridge front. The road log (Figure 1) begins at a field stop described in Bartholomew, Milici, and Schultz (1980).

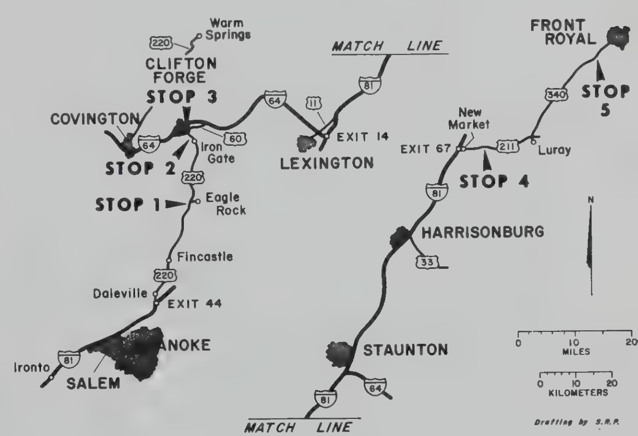

Figure 1. Map of trip route and stop locations.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
0.0	0.0	Begin trip one mile south of Ironto exit on Interstate Highway 81. *Proceed northward* on Interstate Highway 81 and enter area of the Salem syncline which contains rocks ranging in age from Middle Cambrian (Elbrook Formation) to Lower Mississippian (Price Formation). High bluffs to the east are formed of brecciated rocks of the Elbrook Formation (Middle Cambrian) in the hanging wall of the Pulaski thrust system.
1.0	1.0	Exit 38
1.5	0.5	Bluff to west consists of nearly horizontal Upper Devonian Brallier Formation sandstones and shales for next mile.
3.0	1.5	Cross the Pulaski thrust system at crest of ridge and continue on the hanging wall of the thrust for the next seven miles to about exit 40. Mountains to the west are composed of Devonian and Mississippian clastics of the Salem syncline. The distant mountain range to the east contains Chilhowee Group clastics and Precambrian granites and gneisse of the Blue Ridge thrust sheet, which lies north, east and south of Roanoke. The low lands just to the east are Middle and Lower Cambrian carbonate rock units of the Pulaski thrust system (Amato, 1974).
10	7	Exit 40. Leave the Pulaski thrust system and enter the folded and faulted Silurian and Ordovician rocks of the east limb of the Salem syncline (Amato, 1974). Between exits 41 and 43, the low linear

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
		ridge to the west (Green Ridge) marks the outcrop of near vertical Silurian sandstones (Tuscarora Formation).
17	7	Exit 43 Tinker Mountain, ahead and to the west, is separated from the main part of the Salem syncline by the Green Ridge thrust which lies along the eastern base of Green Ridge. The prominent mountains to the east (Reed and Coyner mountains) mark the location of the Reed-Coyner mountain window, where Ordovician through Middle Devonian rocks are within a Cambrian carbonate rock terrain comprised of rocks from both the Salem syncline (west) and the Pulaski thrust system.
21	4	Exit 44. *Leave Interstate Highway 81* at Cloverdale exit and *proceed north* on U.S. Highway 220.
22.5	1.5	Daleville, leave Salem syncline and return to Pulaski thrust system. A transverse thrust ramp separating these structures crosses U.S. Highway 220 in the northern outskirts of Daleville. Locally the Lower Cambrian Rome Formation overlies the Middle Cambrian Elbrook Formation. The low distinctive hills along the trip route are formed by the Rome (McGuire, 1976).
27.1	4.6	East of the highway a segment of the Pulaski fault system has brought brecciated Elbrook dolomites over low dipping Conococheague limestones and dolomites in the "Trinity syncline."
28.9	1.8	Fault slice of the Pulaski thrust system containing Elbrook Formation and reentrant of Middle Ordovician limestones and shales is located on outskirts of Fincastle.
29.3	0.4	Elbrook dolomites exposed on hill to the west in the hanging wall of a thrust; highway is on Middle Ordovician limestones.
30.2	0.9	The Fincastle conglomerate (a part of the Edinburg Formation, Middle Ordovician) is exposed in the overturned limb of a syncline on the east side of the highway. The clasts in the Fincastle and associated conglomerates include recognizable rock fragments from Middle Ordovician through Lower Cambrian formations (McGuire, 1970).
30.5	0.3	Second exposure of Fincastle conglomerate in the upright limb of the fold.
31.0	0.5	Exposures of black fissile shale similar to the Paperville Shale (Ordovician) of Southwest Virginia and the lowermost black shales along the east limb of the Massanutten syncline in northern Augusta County and southern Rockingham County.
35.4	4.4	Middle Ordovician limestones and Beekmantown dolomites are exposed on both sides of the road. These rocks are in the trough of a southwest plunging syncline that has reverse asymmetry (steeper limb to east) as compared with typical Appalachian synclines (McGuire, 1970).
40.3	4.9	Abandoned quarry in overturned Middle and Lower Ordovician limestones in the hanging wall of a fault seemingly associated with the Pulaski thrust system.
40.7	0.4	**STOP 1** — Junction of U.S. Highway 220 and State Highway 43 at a magnificent exposure known as "Eagle Rock" in a gorge on the James River. Rocks of the Martinsburg (Upper Ordovician) to the Needmore(?) (Middle Devonian) formations are repeated by faulting in exposures along U.S. Highway 220. The fault is at the location of the Needmore(?) shale about 350 yards north of the U.S. 220 — State 43 intersection. The section south of the fault is the footwall and the northern part is the hanging wall. It is our interpretation that the fault flattened in the incompetent Needmore(?) shale at the top of a thrust ramp prior to the folding and rotation of the sections. The location of the fault appears to be related to the position of the mid-province structural front and rocks similar to those described at the Fetzer Gap section in Shenandoah County (Rader and Biggs, 1976).

Measured Section: Footwall along U.S. Highway 220 at Eagle Rock exposure beginning at fault about 350 yards north of intersection of U.S. Highway 220 and State Highway 43. Portion below the contorted zone in the Keefer Sandstone modified from Diecchio (1980).

		THICKNESS (FEET)
Fault		
Devonian:		
Needmore shale (3.0′)		
51	Shale, olive-green sheared	3.0±
Licking Creek Limestone (5.0′)		
50	Limestone, medium-gray, laminated, black chert	5.0±
Silurian:		
Clifton Forge Sandstone (5.0′)		
49	Sandstone, light-gray, fine- to medium-grained, cross-bedded	5.0±
Tonoloway Limestone (13.9′)		
48	Limestone, medium- to light-gray with dark shale interbeds, mudcracks	13.9
Wills Creek Sandstone (205.5′)		
47	Sandstone, light-gray to white, fine- to medium-grained, rusty brown on weathering, calcareous, with clay nodules; in part scree covered	10.0

Figure 2. West dipping reverse fault in the Wills Creek Sandstone.

		THICKNESS (FEET)
46	Sandstone, fine- to medium-grained, rusty brown on weathering, calcareous in part, bimodal cross-bedding	55.9
45	Sandstone, light-gray to white, fine- to very fine-grained, bedding thin, some low-angle cross-bedding, ripple marks; about 57 feet above base is a small, west dipping reverse fault (Figure 2); about 115 feet above base is a small anticline	139.6
"Bloomsburg" Formation (60.1', Figure 3)		
44	Sandstone, purple with vertical greenish-gray "burrows"; shale, purple to gray interbedded with white sandstone, 4-inch shale at top of unit	28.7
43	Sandstone, purple to light-gray, fine- to very fine-grained, black cross-beds	15.7
42	Sandstone, purple with green mottles, fine-grained, thin silty shale, vertical greenish-gray "burrows"	15.7
Keefer Sandstone (146' +)		
41	Sandstone, light-gray, very fine- to fine-grained with gray silty shale interbeds	72.4

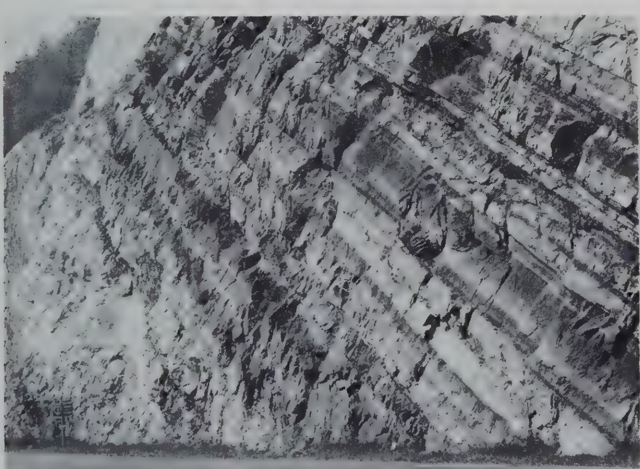

Figure 3. White unit on the left (east) is the Keefer Sandstone. The dark beds are sandstone and shale of the "Bloomsburg" Formation. The light-colored sandstone in the upper right is the Wills Creek Sandstone.

		THICKNESS (FEET)
40	Contorted zone. 90' wide	
39	Sandstone, light-gray, fine-grained, with carbonaceous partings, trails on bedding planes, *Skolithus* and mud-cracks	74.0
Rose Hill Formation (82.7')		
38	Sandstone and clay shale, medium-light-gray, with some red staining	21.0
37	Sandstone, fine- to very fine-grained, grayish-red-purple, hematitic	21.0
36	Interbedded sandstone and clay shale. Sandstone, as above; clay shale, dark-greenish-gray, fissile, trails on bedding planes	26.5
35	Clay shale to silt shale, dark-greenish-gray, fissile; interbedded medium-light-gray sandstone, very thin-bedded	7.5
34	Sandstone, medium- to coarse-grained, grayish-red-purple, hematitic, upper 3.0 feet pebbly, carbonaceous partings, trails on bedding planes; interbedded fine-grained, medium-light-gray sandstone	6.7
Tuscarora Formation (139.8')		
33	Conglomerate, rounded to subrounded quartz pebbles, 0.5 cm maximum diameter, medium-dark, black (carbonaceous?) matrix, carbonaceous partings	0.3
32	Sandstone, medium- to very fine-grained, medium-gray, locally conglomeratic, subrounded quartz pebbles and black siltstone clasts, medium-dark-gray shaly partings	3.0
31	Sandstone, fine- to very fine-grained medium-gray to light-gray, medium- to thick-bedded, *Skolithus*	7.0
30	Sandstone, medium- to fine-grained, light-gray to light-olive-gray, black specks throughout, black cross-beds, interbeds and partings of carbonaceous materials	6.5
29	Sandstone, medium- to fine-grained, medium-dark-gray to light-olive-gray, massive, black stains along joints	12.5
28	Sandstone, medium- to fine-grained, pinkish-gray	2.0
27	Sandstone, fine- to coarse-grained, variegated medium-light-gray, light-gray and light-brown, cross-bedded	2.5
26	Sandstone, fine- to very fine-grained, medium- light-gray, massive	15.0
25	Sandstone, fine- to very fine-grained, very light-gray, massive-bedded	2.5
24	Sandstone, fine- to very fine-grained, medium-light-gray, massive	5.0
23	Sandstone, fine- to very fine-grained, very light-gray, medium-bedded	2.0
22	Sandstone, fine- to very fine-grained, medium-light-gray, massive	6.0
21	Conglomeratic sandstone, medium- to coarse-grained, light-gray, weathers light-brown, quartz pebbles, 1 cm maximum diameter	3.0
20	Carbonaceous silt shale	1.0

		THICKNESS (FEET)
19	Sandstone, very fine-grained, grayish-orange, massive	4.0
18	Sandstone, coarse- to fine-grained, light-gray, some medium-dark-gray beds in upper 4 feet, cross-bedded, olive-gray shale clasts	26.0
17	Sandstone, medium- to fine-grained, medium-light-gray, weathers very pale-orange to light-brown, medium- to very thin-bedded, cross-bedded, rare olive-gray shale clasts	20.0
16	Sandstone, fine- to very fine-grained, light-gray, massive-bedded, cross-bedded	1.5
15	Sandstone, medium- to fine-grained, very light-gray, weathers light-brown, medium- to very thin-bedded, cross-bedded	2.5
14	Sandstone, fine- to very fine-grained, medium-light-gray, cross-bedded, black joint surfaces, some yellowish-gray, 2-cm shale beds in upper 2-feet	7.0
13	Sandstone, fine- to very fine-grained, weathers light-brown, medium- to thick-bedded, cross-bedded, interbedded light-olive-gray silt shale in upper 6 feet	10.5
Ordovician:		
Oswego Sandstone (36′)		
12	Siltstone, light-olive-gray, weathers light-brown, good cleavage; 5-cm bed of sandstone, fine-grained, light-gray, at 3 feet above base of interval	4.5
11	Interbedded sandstone and siltstone, sandstone, fine- to very fine-grained, medium-light-gray to light-olive-gray, medium-bedded, cross-bedded; siltstone, light-olive-gray, weathers light-brown	3.0
10	Sandstone, fine- to very fine-grained, light-bluish-gray, weathers light-brown, thick- to very thin-bedded, cross-bedded, occasional clasts and interbeds of light-olive-gray silt shale, 1 cm maximum clast size	4.0
9	Interbedded litharenite and siltstone: Litharenite, fine- to very fine-grained, medium- light-gray, weathers pale-yellow-brown to pale-brown, thick-bedded, micaceous, cross-bedded, some siltstone clasts; siltstone, light-olive-gray; weathers light-brown	3.0
8	Sandstone, fine- to very fine-grained, light-blue-gray, weathers light-brown, very thin- to thick-bedded, cross-bedded, interbeds and clasts of light-olive-gray silt shale, 2 cm maximum clast size, carbonaceous partings, black silt-shale interbedded at 4 feet below top of interval	11.5
7	Siltstone, medium-gray, weathers light-olive-gray, medium-bedded	1.5
6	Litharenite, fine- to very fine-grained, greenish-gray, weathers light-brown, medium- to very thin-bedded; interbeds of medium-gray silty shale, weathers light-olive-gray, channeling	8.5
Martinsburg Formation (upper 52.5′)		
5	Siltstone, medium-gray, weathers light-olive-gray, medium-bedded, slightly micaceous, some medium-light-gray sandstone stringers, 2-cm beds of fossiliferous sandstone at middle of interval *(Lingula)*, channeling	2.0
4	Siltstone, fossiliferous, olive-gray, *Lingula*, gastropods, fossiliferous beds are phosphatic, some beds of *Lingula* coquina, occasional carbonaceous(?) partings; medium-bedded, brownish-gray sandstone at 1.5 and 3 feet above base	13.0
3	Sandstone, very fine-grained, dark-gray to brownish-gray with white specks that weather light-brown, with interbedded olive-gray, medium- to thick-bedded siltstone	7.5
2	Siltstone, fossiliferous, olive-gray, weathers brownish-gray, *Lingula*	3.0
1	Interbedded sandstone and shale, sandstone, fine-grained, medium-gray to medium-dark-gray, rare white specks that weather grayish-orange, very thin- to thick-bedded; silt shale to clay shale, medium-dark-gray, sandstone increases upward	27.0

END OF SECTION

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
41.8	1.1	The steep, low, wooded hills to the west are characteristic of the geomorphic forms developed on the Brallier Formation. Brallier and Millboro formations (Devonian) are exposed for the next nine miles.
51.5	9.7	At the south (near) end of the bridge over the James River are good exposures of Devonian rocks; the Ridgeley (Oriskany) Sandstone and the uppermost Helderburg limestone (Licking Creek Limestone).
52.9	1.4	Town of Iron Gate.
54.3	1.4	Rainbow arch, northern part of the Rich patch anticline.
55.9	1.6	Junction of U.S. highways 220 and 60 in Clifton Forge. *Turn left* on U.S. 60/220 and proceed westward.
57.0	1.1	Intersection U.S. Highway 60/220 and Interstate Highway 64, *proceed west* on Interstate 64 to Covington.
65.3	8.3	The anticline to the north is in the Licking Creek Limestone; this structure and parallel structures plunge obliquely into the Rich Patch anticline (Figure 4). This junction of stuctures forms a major lineament that separates the Central Appalachian fold trends from the Southern Appalachian fold trends.

Figure 4. Anticline in the Licking Creek Limestone (Devonian) along the Jackson River, view to the north.

Figure 5. View to south of Rainbow arch from Clifton Forge. Note the west dipping reverse fault cutting ledges of Keefer Sandstone.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
68.0	2.7	Exit Interstate Highway 64 west at U.S. Highway 220 and re-enter I-64 headed east.
79.2	11.2	*Proceed eastward* on Interstate Highway 64 to the first Clifton Forge exit. Follow U.S. Highway 60/220 eastward through Clifton Forge to intersection of U.S. highways 60 (east) and 220 (south).
80.3	1.1	*Turn right* (south) on U.S. Highway 220 and proceed to Iron Gate Community and *turn around.*
84.4	4.1	**STOP 2** - *Pull off to right* in Iron Gate (Rainbow) gorge. Exposure of a classic western Virginia anticline. From the center of the arch at water level of the Jackson River, a normal sequence Martinsburg Formation (Upper Ordovician) through the Keefer Formation (Silurian) is well exposed (Figure 5). The lower part of the arch is formed by the Tuscarora Formation (Silurian) and the upper part by the Keefer Formation (Lesure, 1957). (Stratigraphic relationships between Eagle Rock, Iron Gate and Warm Springs are shown in Figure 6). The fold is strongly asymmetric with a well-defined kink fold on the west limb. A northwest dipping reverse fault in the west crest is visible only from the Clifton Forge area. This anticline, as well as most other western Virginia anticlines, was probably generated along a ramp thrust arising from a decollement in the subsurface. A question arises concerning the origin of this anticline: Does the ramp-thrust zone crop out or does it stay in the Upper Ordovician shales (Martinsburg/Reedsville) of the subsurface? If it comes to the surface, the logical horizon for flattening would be the Millboro-Needmore shales at intervals

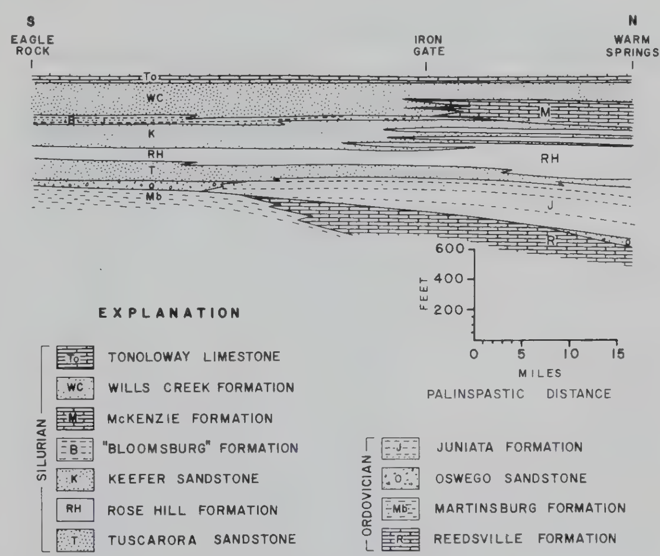

Figure 6. Stratigraphic relationships of sections at Eagle Rock, Iron Gate, and Warm Springs. See Figure 1 for locations. Note the increase in sandstone to the south toward Eagle Rock.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
		containing Tioga metabentonite beds, which occur throughout several hundreds of feet of the shales in this area. These formations are at the surface along the west flank of the anticline to be seen at Stop 3 and extend beneath the broad expanses of Upper Devonian clastics in synclines to the north. A decollement beneath the Upper Devonian rocks of Brailler Formation would help to explain the intense folding in the Brailler south of Douthat State Park and along State Highway 42.

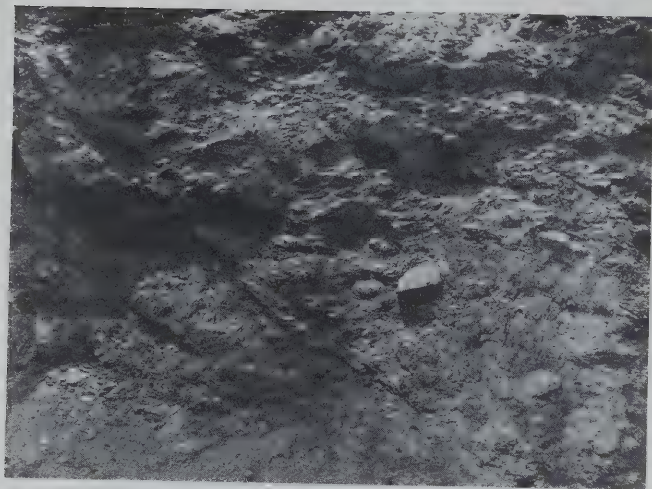

Figure 7. Millboro Shale breccia at Stop 3 containing rotated concretions and light-colored blocks of Needmore shale.

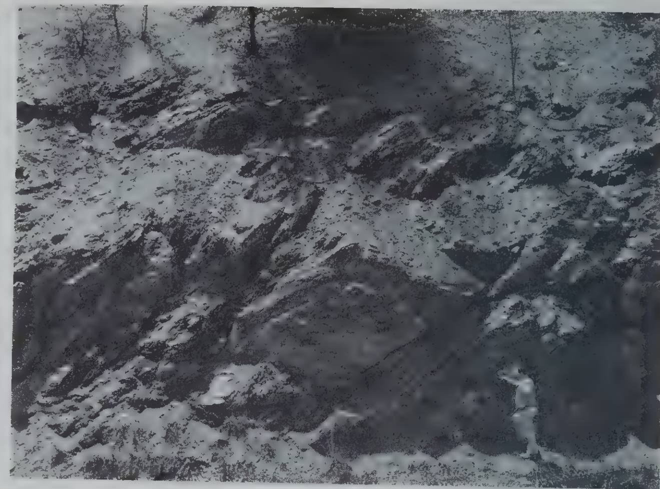

Figure 8. Millboro Shale breccia containing, bedded blocks of Needmore shale.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
86.2	1.8	Return to intersection of U.S. Highway 60 and 220 in Clifton Forge. *Turn right* at traffic light onto U.S. Highway 60 east.
86.4	0.2	**STOP 3** - Park on left at Motor Sales Corporation and walk back to west to community park. This exposure of fracture porosity in the Millboro and Needmore shale is at the lowest exposed point in the northwestern part of the Iron Gate anticline. Strongly cleaved to pulverized Millboro Shale and shale breccia surround intensely fractured to brecciated blocks of Needmore(?) shale (Figure 7). Rock type and fabric in these exposures are similar to those in the breccia zones (Max Meadows breccia) associated with the Pulaski decollment to the east and to the fabric developed in the Chattanooga shale beneath the Pine Mountain thrust in Southwest Virginia. *Proceed east* on U.S. Highway 60.
87.9	1.5	Intersection of U.S. Highway 60 and Interstate Highway 64; *proceed eastward* on I-64.
88.4	0.5	On right are exposures of Millboro Shale showing features similar to those seen at last stop (Figure 8).
90.7	2.3	To the west are bluffs composed of the Brallier Formation that display disharmonic and kink-band type folds that are characterisitc of folds in this rock unit west of the Rich Patch anticline and the anticline that conincides with Mill Mountain (ahead and to the left beyond the bluffs).
91.8	1.1	Cowpasture River.
92.6	0.8	Helderburg limestones and Oriskany sandstones exposed on the left in the road cut.
95.5	2.9	Long Dale furnace; site of early iron ore smelting in the Clifton Forge iron district.
110.5	15.0	Mile post 50, Trace of North Mountain fault; Conococheague rocks thrust over Beekmantown rocks.
113.9	3.4	Maury River.
115.7	1.8	Junction of U.S. Highway 11 and Interstate Highway 64; continue east on Interstate 64.
116.5	0.8	Exit 14, Junction of Interstate highways 64 and 81; proceed north on Interstate Highway 81. The Staunton fault zone parallels the highway to exit 52, where the highway crosses onto the upper plate.
127.2	10.7	Mile post 202, Linear ridge to the west is developed on steeply inclined sandstones of the Conococheague Formation.
131.2	4.0	Mile post 206. Brownish scar at base of mountain to the east is clay in the Cold Spring kaolinite pits located at the west foot of the Blue Ridge Mountains and on the drainage divide between the Shenandoah and James River systems. These residual clay deposits are developed from Lower Cambrian limestones and shales and have been protected from erosion by their position on the drainage divide.
146.5	15.3	Exit 57. Conical wooded hills to the west are developed from massive chert beds in the Beckmantown Formation.
158.9	12.4	Exit 60. Recross the Staunton fault and enter the North Mountain fault block.
164.8	5.9	Mole Hill, the conical-shaped hill to the north-west, is an olivine basalt plug of Eocene age.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
170.9	6.1	Exit 64, Harrisonburg, Note Massanutten Mountain to the east; its southern end is the south western limit of Silurian sandstones in Shenandoah Valley.
181.3	10.4	Exit 66, Mauzy. Ten miles to the west at Brocks Gap an anomalous Upper Ordovician-Lower Silurian sandstone section is exposed. An interpretation of this section is in Rader and Perry (1976).
188.2	6.9	Exit 67, New Market. *Turn right* onto U.S. Highway 211 east.
188.7	0.5	Junction of U.S. highways 211 and 11. *Turn left* and proceed north on U.S. Highway 11/211.
188.9	0.2	Junction of U.S. Highway 211 and 11. *Turn right* and proceed east on U.S. Highway 211. Note the prominent wind gap to the east. This gap, New Market Gap, occurs at a structural high in the plunge of the Massanutten synclinorium, where the Massanutten Sandstone is breached.
192.7	3.8	**STOP 4** - New Market Gap. Exposures east and west of gap. During the late Middle and Late Ordovician the eastern portion of the Appalachian miogeocline was subsiding rapidly and receiving sediments from the east. Some formed turbidites. Typical base - and top-truncated Bouma cycles are preserved in the Martinsburg Formation in the Massanutten synclinorium. The Martinsburg is overlain by the Massanutten Sandstone (Lower and Middle Silurian). The deposition history of the Massanutten Sandstone has been described by Roberts and Kite (1978). Proceed east on U.S. Highway 211 to Luray.
195.7	3.0	Typical Martinsburg turbidites are exposed at places along the highway for three miles.
198.2	2.5	South Fork Shenandoah River. In this area disharmonic, recumbent folds and klippen are in rocks underlying the Martinsburg Formation.
200.9	2.7	Luray Caverns on left in the Lower Ordovician Beekmantown Formation. Continue on U.S. Highway 211 bypass.
202.9	2.0	Junction of U.S. highways 211 bypass and 340. *Turn left* onto U.S. 340 north. Proceed toward Front Royal. From here to Stop 5 the trip route traverses Upper Cambrian and Lower Ordovician carbonate rocks.
210.3	7.4	Rileyville.
212.3	2.0	Compton.
216.6	4.3	Bentonville.
219.3	2.7	Limeton.
221.2	1.9	**STOP 5** - Gooney Creek campground. Pull into campground and park. Along Gooney Run, at the south side of the campground, granodiorite of the Pedlar Formation(?) (Precambrian) is on overturned beds of the Lower Ordovician Beekmantown Group. Contact zone is about 150 yards east of U.S. Highway 340 bridge over Gooney Run. Seismic and deep drilling data (Harris, 1979; Harris and Bayer, 1979a, 1979b; and Cook and others, 1979) provide evidence for a model that explains the relationships between the structural styles of the Valley and Ridge and Blue Ridge. According to Harris (1979) the rootless Blue Ridge anticlinorium was thrust west on a subhorizontal fault which ramped upward from a master decollement. Harris (1979) and Harris and Bayer (1979a) suggest that Valley and Ridge rocks extend beneath the Blue Ridge anticlinorium.

END OF ROAD LOG

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PART II: AREA NORTH OF ABINGDON ALONG U.S. 58A/19

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CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
0.0	0.0	Begin road log at the intersection of U.S. 11 (West Main St., Abingdon) and U.S. 19 about one mile west of the main business district of Abingdon. (Figure 1).
0.2	0.2	Proceed north on U.S. Highway 19. The first rock exposures on the right (east) are interbedded limestones and dolomites of the Conococheague Formation (Upper Cambrian); beds are inclined very steeply to the south or partially overturned to the north. These overturned strata are on the southeast limb of a thrust faulted anticline. Just north are vertical, thin-bedded limestones of the Nolichucky Formation.
0.4	0.2	Intersection at right (east) with U.S. Highway 58 alternate; continue north on U.S. 58 A/19.
0.9	0.5	In right bank are exposures of fractured, gently inclined Honaker dolomite. State Road 848 (Old Cummings Heights Road) intersection from east.
1.3	0.4	Appalachian Power Company substation on right. A small thrust fault was mapped about 100 yards north of this location.
1.7	0.4	Scattered exposures of Honaker Formation limestones and dolomites define the surface axial trace of the Cummings Heights syncline.
2.0	0.3	Outcrops on right are Honaker dolomite beds which dip south into the Cummings Heights syncline.
2.5	0.5	At right are low-dipping, thin-bedded limestone and shale of the Nolichucky. This outcrop is in a fault-bounded slice in the base of the Pulaski thrust fault.
2.8	0.3	Cross area of major offset along Pulaski thrust fault, where the Honaker Formation (Middle Cambrian) is thrust onto upper Knox dolomites (Lower Ordovician) with displacement of about 6000 feet.
3.0	0.2	Upper Knox dolomite dips southward and forms the upper portion of the Saltville thrust plate.
3.4	0.4	Carvosso United Methodist Church on right is on a narrow outcrop belt of the basal Ordovician Chepultepec Formation. Charles Butts was the first to note characteristic cephalopods at this locality.
3.5	0.1	There are good exposures on right of the upper portion of the Copper Ridge Formation (Upper Cambrian) which is dominated by dolomite but contains some limestone, chert and distinctive brownish sandstone interbeds.

Figure 1. Location Map. Measured section begins 0.1 mile north of Greendale Community.

CUMULATIVE MILEAGE	INTERVAL MILEAGE	EXPLANATION
3.9	0.4	Opposite the Sunoco Service Station a wall built by the highway department restrains portion of weathered carbonates of the lower part of the Copper Ridge Formation in a landslide-prone area.
4.1	0.2	Shales and thin-bedded limestones of the Nolichucky Formation are on the right. The beds contain brachiopods, trilobites and cystoid plates. Shale increases in the Formation to the north and is dominant here.
4.2	0.1	The lower portion of the Nolichucky here contains several interformational limestone-pebble conglomerates (note the exposure adjacent to the "no parking" sign (Figure 2).
4.4	0.3	On left (west) is medium-bedded dolomite of the Honaker Formation.
4.5	0.1	Greendale Community; State Road 700 intersection.
4.6	0.1	Cross surface trace of Saltville thrust fault which here has a displacement of over 15,000 feet. Honaker Formation (Middle Cambrian) is thrust onto the Pennington Formation (Upper Mississippian). Both formations are partly covered.

Figure 2. Intraformational limestone-pebble conglomerate in lower Nolichucky.

In the following measured section, 5146.9 feet of Mississippian rocks and older rock units are described. Portions of this section were first described by Averitt in 1941. The author sampled and described the section in 1968. The portion of the section herein described for the Maccrady and Price formations was sampled in 1970 and included in the author's dissertation on Lower Mississippian stratigraphy (Bartlett, 1974, p. 232-236.) Slagle (1978) recently studied the Hillsdale Limestone paleontology and paleoecology at exposures in the section. Schmidt (1973) sampled the Price Formation on this outcrop in his regional study. Near Benhams (about 10 miles to the southwest) 7080 feet of Mississippian rocks, possibly representing the thickest accumulation of Mississippian age deposits in North America, were traversed in an exploratory well drilled in early 1981 by Highlander Resources. The well was spudded in the Pennington Formation. Mileage from Abingdon on left side of column.

	UNIT NO.		THICKNESS (FEET)
		Mississippian:	
		Pennington Formation (854+ feet)	
		First (southernmost) 150 yards of exposure forms a small anticlinal fold which is a repeat of units 191-188. Normal fault, displacement approximately 180 feet, lies in gully on left side of highway.	
	191	Shale, brownish-gray, and siltstone, dense, medium-to thin bedded, with occasional fossils	106
	190	Shale, greenish-gray and reddish-brown, fissile, and siltstone, medium-bedded	38
	189	Shale, gray, with some gray, argillaceous thin-bedded fossiliferous limestone, and some siltstone with rounded shapes suggesting slumping contemporaneous with deposition	12
	188	Sandstone and siltstone, gray, weathers to brown, calcareous, medium-to thin-bedded, fossiliferous, with thin gray shale partings	34
	187	Siltstone, gray, weathers to brown, dense, medium-bedded with fossiliferous layers including the pelecypod *Sulcatopinna missouriensis* (Swallow), nautiloids, and spiriferid and productid brachipods	45
	186	Argillaceous limestone, gray, thick-bedded; with abundant fossils throughout: *Pentremites* blastoids, fenestrate bryozoans, five species of brachiopods, two species of pelecypods, crinoids and a horn coral	67
	185	Silty shale, gray, very carbonaceous grades upward in unit to calcareous siltstone	32
	184	Silty shale, reddish-brown, calcareous, hackly, with abundant carbonaceous plant fragments on some bedding planes	15
	183	Sandstone, dark-red-brown, very fine-grained, thick-bedded	7
	182	Sandstone, gray, very fine-grained, medium-bedded, with abundant plant fragments, with shale interbeds	21
	181	Sandstone, gray, very fine-grained, thin-bedded; some shale, greenish-gray	5
	180	Silty shale, dark-red and purplish-brown, fossiliferous with three species of pelecypods, worm-trail-like markings and plant fragments; few thin interbeds of purplish-brown, very fine-grained, calcareous sandstone	13
4.95	179	Siltstone, gray, thick-bedded, with very large crinoid stem sections	32
	178	Shale, gray	1
	177	Siltstone, gray, dense, fossiliferous	3
	176	Silty shale, gray	6
	175	Siltstone and sandstone, very fine-grained, gray thick-bedded with some interbedded shale; some zones of abundant large crinoid stems (Figure 3)	14
	174	Silty-shale, gray	6
	173	Siltstone and sandstone, as unit 175	23
	172	Shale with scattered rounded siltstone "balls" to 2.5 feet in diameter suggesting	

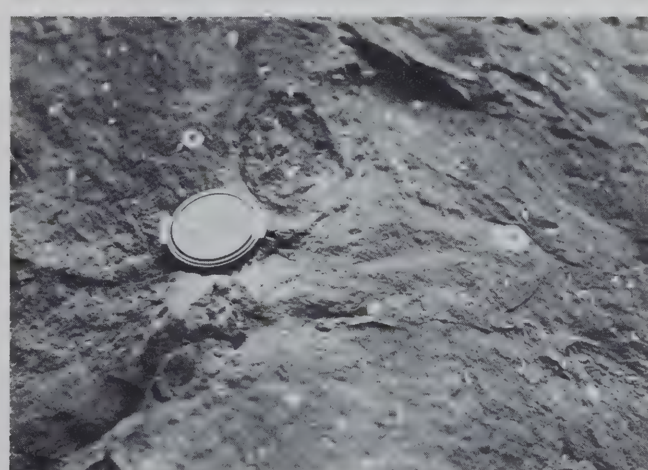

Figure 3. Limy siltstone containing abundant large crinoid columnal sections in upper Pennington Formation (measured section unit #175).

Figure 4. Penecontemporaneous slump "balls" of limy siltstone enclosed in shale of Pennington Formation (measured section unit #172) on east side of U.S. 19-58 A. Sledge hammer is 90 cm long. Dip is 25°southeast toward Saltville fault which has concealed the axis of the Greendale syncline.

	UNIT NO.		THICKNESS (FEET)
		slumping contemporaneous with deposition. Exposed in high roadcut (Figure 4)	17
	171	Siltstone and argillaceous sandstone, gray, thin-to medium-bedded; moderately fossiliferous with brachiopods and large crinoid stems	90
	170	Sandstone, light-gray, very fine-grained with large carbonized plant stems	5
	169	Siltstone and sandstone, gray, very fine-grained, calcareous, with large productid brachiopods	55
	168	Silty to sandy shale, gray, with spheroidal weathering	18
	167	Shaly sandstone and siltstone, gray; fossils include pelecypods and productid brachiopods	36
	166	Shale, gray, platy, brittle, very fine-grained sandstone beds which become more numerous toward upper part of unit; strike N 20° E, dip 25° SE. Base of Pennington exposed at house on east side of highway	153
5.1	Cove Creek Limestone (876 feet)		
	165	Argillaceous limestone, gray, dense, thick-bedded	143
	164	Ferruginous limestone, dark-red-brown, medium-bedded, with abundant bryozoans in lower part	28
	163	Limestone, gray, dense	114
	162	Limestone, gray, dense, thick-bedded; zones of abundant fossils which contain brachipods and bryozoans including *Archimedes* sp	31
5.35	161	Limestone, gray, dense, fossils rare; becomes shaly in middle part (best exposed on west side of road)	287
	160	Shale, black to dark-gray, crumpled, with slickensides	3
	159	Limestone, dark-gray, dense, thick-bedded, dip 28° SE	135

	UNIT NO.		THICKNESS (FEET)
	158	Covered	60
	157	Argillaceous limestone, gray, thinly-laminated to medium-bedded, weathers to shaly appearance, dip 23° SE	75
5.5			
	Fido Sandstone (43 feet) (exposed best on west side of highway)		
	156	Very sandy limestone, dark-red-brown, cross-bedded; weathers to friable sandstone	38
	155	Hematitic sandstone, dark-brown, medium-grained, subangular to subrounded, thick-bedded, friable	5
	Gasper limestone (738 feet)		
	154	Argillaceous limestone, gray, thick-bedded; crinoidal near top and with abundant *Pentremites* blastoids	78
	153	Argillaceous limestone, gray, partly covered	39
	152	Argillaceous and crinoidal limestone, gray, thick-bedded	50
	151	Crinoidal limestone, dark-red-brown, medium-grained, thick-to medium-bedded, with three species of crinoids, numerous *Pentremites* blastoids and brachiopods	53
	150	Argillaceous limestone, gray, weathers to shaly appearance; poorly exposed	39
	149	Crinoidal limestone, light-gray, coarse-to medium-grained, medium-bedded	10
	148	Argillaceous limestone, gray, thick-bedded; poorly exposed	469
5.9	Ste. Genevieve Limestone (1029 feet)		
	147	Ferruginous, crinoidal limestone, dark-red-brown, thick-bedded	18
	146	Argillaceous limestone, gray, shaly weathered appearance	12
	145	Ferruginous limestone, dark-red-brown, medium bedded	32
	144	Argillaceous limestone, gray, weathers to brown, thick-bedded, zones of rounded clay pebbles	25
	143	Shaly limestone, gray, very thin-bedded	8
	142	Sandstone, brown, fine-grained	1
	141	Argillaceous limestone, gray, weathers to brown, medium-bedded	8
	140	Limestone, gray, coarse-grained; fossils include bryozoans, brachiopods and crinoids	2
	139	Argillaceous limestone, gray, weathers to brown	75
	138	Shaly limestone, light-gray, weathers to brown; partly covered	24
	137	Calcareous sandstone, gray-brown, fine-grained, dense, thin-bedded	10
	136	Argillaceous limestone, gray, weathers to shaly appearance	30
	135	Calcareous sandstone, gray, very fine-grained, uneven bedding, with scattered, rounded, gray-shale pebbles and shale partings; locally is siltstone	47

UNIT NO.		THICKNESS (FEET)
134	Argillaceous limestone, light-gray, weathers to brown, shaly appearance	70
133	Shale, brown, slightly silty, sub-fissile	12
132	Argillaceous limestone, gray, dense, thin-to medium-bedded	55
131	Limestone, gray, dense, medium-bedded	62
130	Crinoidal limestone, gray, coarse-grained, medium-bedded	16
129	Shaly limestone, gray, laminated with carbonaceous fragments on partings	8
128	Limestone, greenish-gray, to dark-gray, coarse-grained, thick-bedded; sulfur odor on fresh break in top layers; fossils include brachiopods and crinoids	7
127	Argillaceous limestone, weathers to brown clay	45
126	Limestone, dark-gray, coarse-grained, thick-bedded; strong sulfur odor on fresh break; very fossiliferous with brachiopods and crinoids	8
125	Shaly limestone, light-blue-gray, silty, hackly	43
124	Argillaceous limestone, gray, thin-bedded, weathers to brown silty clay.	60
123	Limestone, gray, thinly-laminated to medium-bedded, ripple-marked	5
122	Limestone, light-gray, coarse-grained, thick-bedded, fossiliferous	16
121	Argillaceous limestone, gray, dense, thick-bedded	10
120	Argillaceous limestone, light-gray, laminated, weathers to shaly appearance	1
119	Limestone, light-gray, coarse-grained, with greenish-gray, widely spaced silty laminae	11
118	Siltstone, gray-green, laminated reddish-brown, thick bedded	13
117	Limestone, light-gray, coarse-grained, fossiliferous, oolitic	1
6.5 116	Interbedded limestone, gray, coarse-grained and siltstone, gray-brown, thick-laminated, cross-bedded; with some reddish-to greenish-gray silty shale partings	14
115	Limestone, gray, coarse-grained, medium-bedded, with layers of laminated greenish-gray siltstone	64
114	Argillaceous limestone, gray, with abundant gray chert nodules, thick-bedded	7
113	Calcareous siltstone, gray, weathering to gray-green, dense, thick-to massive-bedded; shattered zone near base with calcite veinlets	18
112	Crinoidal limestone, light-gray, coarse-grained, medium-bedded, fossils include crinoids, brachiopods and horn corals	10
111	Argillaceous limestone, light-gray, weathers to light-brown, thick-bedded, very fossiliferous including fenestrate bryozoan, productid brachiopods and horn corals	52
110	Shale, black, fissile, calcareous, fossiliferous	2
109	Shaly limestone, gray	10
108	Limestone, gray, dense, thick-bedded	2
107	Limestone, gray, fine-grained, thick-bedded, with crinoidal zones with abundant crinoid *Platycrinus penicillus* (Meek and Worthen), also horn corals	34
106	Crinoidal limestone, dark-gray, grades toward top of unit into cherty limestone with irregular and rounded, gray chert nodules, partly algal banded	78
105	Oolitic limestone, light-gray, thick-bedded	3
6.5	Hillsdale Limestone (267.4 feet)	
104	Limestone, light-gray, weathers to greenish-gray, very fossiliferous including spiriferid brachiopods, nautiloids, bryozoan, and a horn coral; weathers to shaly appearance	30
103	Limestone, gray, dense, some shaly partings; zone of gray, algal-chert nodules in middle of unit; fossiliferous, especially in upper portion of unit (Figure 5)	41
102	Shale, dark-gray to black, fissile	1
101	Argillaceous limestone, dark-gray, thick-bedded, slightly fossiliferous	21
100	Argillaceous cherty limestone, dark-gray, with abundant algal banded gray chert nodules	1
99	Argillaceous cherty limestone, dark-gray, abundant light-gray to gray, partly algal-banded chert nodules, massive-bedded, fossils rare, dip 21° SE	40.7
98	Oolitic limestone, light-gray, medium-to coarse-grained, with well-rounded ooids; middle of unit with non-oolitic layer	15

Figure 5. Algal-banded and siliceous fossiliferous chert nodules in Hillsdale Limestone (measured section unit # 103). On freshly broken pieces the rock smells of petroleum.

	UNIT NO.		THICKNESS (FEET)
	97	Limestone, dark-gray, dense, thick-bedded, in part argillaceous, very fossiliferous throughout (abundant bryozoan, three species; three species of brachiopods, pelecypods, crinoids, horn coral and the tabulate coral *Syringopora virginica* Butts)	101.7
	96	Shaly limestone, gray, fossiliferous	16
6.7		Little Valley Formation (549 feet; base of formation covered). (Highway "curve" sign is located near this boundary). Note: At the western edge of Washington County, about 15 miles southwest of here, is located the Early Grove Gas Field which has production from the Little Valley Formation and the upper sandstone member of the Price Formation.	
	95	Shale, gray, calcareous	13
	94	Limestone, gray, medium-grained, fossiliferous	1
	93	Shale, black, coaly, with lustrous surfaces, contorted	3
	92	Agillaceous limestone, gray, dense to shaly, strong odor in fresh break in lower part; very fossiliferous with abundant bryozoans, three species of brachiopod, and a horn coral, dip 27° SE	82
	91	Shale, dark-gray, fissile, with one thin bed of dense limestone near top, fossiliferous in part	40
	90	Argillaceous limestone, gray, dense, abundant fossils with bryozoan and productid brachiopods	28
	89	Shaly limestone and shale, gray, calcareous, slightly fossiliferous	17
	88	Limestone, gray, dense, strong sulfur odor on fresh break, with a few gray chert nodules in upper part; coral bioherm composed of large colony of tabulate corals (exposed in highway median area)	12
	87	Shaly limestone, gray, thinly-laminated, rare fossils	5
	86	Siltstone and sandstone, brown to light-gray, very fine-to fine-grained, calcareous	5
	85	Limestone, gray, dense, sulfur odor on fresh break, calcite-lined geodes to 0.5 inch diameter common, thick-bedded; sparsely fossiliferous	5
	84	Shaly limestone, dark-gray, with two dense argillaceous limestone beds in middle portion, abundant fossils with three species of brachiopods, four species of bryozoans, two species of pelecypods, crinoids, horn and colonial rugose corals	50
	83	Limestone, blue-gray, medium-grained, with dark-gray rounded chert nodules, thick-bedded; fossils include brachiopods, bryozoans, and crinoids	22
	82	Calcareous sandstone, light-gray, weathers to brown, very fine-grained, medium-bedded, grades upward to arenaceous limestone, fossiliferous	10
	81	Argillaceous limestone, dark-gray, medium-bedded, with brachiopods in upper part	20
6.85	80	Covered, formerly partly exposed before road was rebuilt. Averitt (1941, p. 16) and Butts (1940, p. 356) found 90 feet of partially exposed sandstone and limestone which could be assigned to the Little Valley Formation. The North Fork of the Holston River conceals an additional 146 feet of section which includes the lower beds of the Little Valley Formation	236
		Maccrady Formation (39.2 feet) (Partial exposure on State Road 611 about ½ mile west of U.S. 19-58A).	
	79	Mostly covered by State Road 611, upper part of unit is exposed above road on south bank of river. Clay shale, partly silty, pale-olive, yellowish-gray, and grayish-red. Yellowish-gray shale is dolomitic	39.2
7.1		Price Formation (751.3 feet) Hayters Sandstone Member (137.8 feet)	
	78	Arkosic sandstone, fine to medium-grained, subrounded, light-gray-brown, coarse muscovite flakes, fair porosity; contains one-inch-thick layer of quartz-pebble conglomorate with pebbles to 15 mm	8.5
	77	Sandstone, very fine-grained, angular, medium-gray, sparsely carbonaceous, very fine to medium muscovite, medium-bedded, tabular cross-laminated, rare imprints of brachiopods; about 8.5 feet above base is a interval of quartz pebbles to 20 mm., another pebble interval at 12.0 feet above base of unit. At base is thin parting of slightly silty shale, micaeous, light-gray	18.0
	76	Arkosic sandstone, coarse- to very coarse-grained, with scattered quartz pebbles, and subrounded pebbles to 49 mm on upper bedding plane, pale-yellowish-brown	5.0
	75	Arkosic sandstone, very fine-grained, olive-gray, trace of very shiny coal grains, fine muscovite flakes, medium-bedded, thin-laminated	8.5
	74	Covered interval	4.0
	73	Arkosic sandstone, fine- to medium-grained, with rare coarse grains, subangular pebbles to 20 mm on top bedding plane, grayish-brown, medium-bedded, cross-laminated, cross-bedding dipping 26° E and 28° S60°E, top surface wavy	7.0
	72	Arkosic sandstone, fine- to medium-grained, subangular, very pale-orange feldspar grains, few flakes muscovite,	

	UNIT NO.		THICKNESS (FEET)
		scattered rounded quartz pebbles to 8 mm, mostly in upper part	4.8
	71	Concealed by river terrace gravels	43.0
	70	Partly covered. Interbedded coarse siltstone to very fine-grained sandstone, light-gray, very fine muscovite, very thin-bedded and silty shale	8.0
	69	Interbedded argillaceous sandstone, very fine-grained, slightly glauconitic, dense, light-olive-gray, carbonaceous, few imprints of *Chonetes* sp. and *Productella* sp. brachiopods, and coarse siltstone, medium-gray, trace amounts of very fine muscovite, some spheroidal weathering	31.0
		Greendale Member (290.2 feet) (Exposed in bank behind ARCO service station across the highway from intersection of State Road 8)	
7.3	68	Interbedded argillaceous siltstone, light-gray, very fine muscovite; sandstone, very fine-grained, slightly glauconitic, light-olive-gray, glauconite very dark-green, very fine muscovite, fossil fragments, very thin-bedded and silty shale, medium-light-gray, carbonaceous; siltstone/sandstone ratio 1/2.	27.5
	67	Silty shale, slightly glauconitic, light-olive-gray, glauconite very dark-green, very fine muscovite, partly weathers spheroidal, few fossils in thin ferruginous bed, with *Spirifer* sp. and *Syringothyris* sp	24.8
	66	Argillaceous siltstone, light-gray, partly ferruginous, light-olive-gray, very fine muscovite, about 10.0 feet above base some molds of *Spirifer* sp.; some silty shale in upper part, light-gray, slightly glauconitic, very fine muscovite	15.8
	65	Sandy siltstone, slightly glauconitic, light-gray, partly stained brown, very fine quartz grains, very fine muscovite, fossiliferous, with *Spirifer bifurcatus(?)* *Productella* sp., and *Spirifer solidirostris(?)* brachiopods, *Fenestrellina* sp., *Cystodictya* sp. bryozoans, and crinoid columnals.	3.5
	64	Glauconitic shale, silty, dusky-yellowish-green to grayish-green, very fine muscovite, glauconite most abundant in two beds 0 to 0.5 feet and 4.3 to 5.5 feet above base	5.5
	63	Silty shale, medium-light-gray, very fine muscovite, very fossiliferous with imprints of *Syringothyris texta*, and *Productella* sp. brachiopods, *Fenestrellina* sp., *Rhombopora* sp. bryozoans, large pectenoid clam (44 mm by 46 mm) crinoid columnals, and carbonaceous plant stems	6.0
	62	Very slightly silty shale, light-olive-gray, very fine muscovite, hackly	9.0
	61	Glauconitic siltstone and silty shale with glauconite concentrated in four zones at 3.0-4.0, 6.0-6.5, 9.9-10.4, and 21. 3-24.3 feet above unit base; fossil imprints, mainly in upper zone, include *Chonetes* sp., and *Spirifer winchelli* brachiopods, *Fenestrellina* sp. and *Rhombopora* sp. bryozoans, ostracodes, and crinoid columnals	24.3
	60	Glauconitic shale, very silty, dusky-yellowish-green, glauconite very fine-grained, very fine muscovite, and siltstone, fossiliferous, trace amounts of scattered glaucontie, light-yellowish-brown, very fine muscovite, fossils include *Fenestrellina* sp. and *Rhombopora* sp. and crinoid columnals	2.0
	59	Interbedded very silty shale, grayish-brown, micaceous, and siltstone, light-grayish-brown, very fine muscovite, scattered dark-green, very fine to fine grains of glauconite	26.0
	58	Covered interval	75.4
	57	Poorly exposed. Slightly silty shale, grayish-orange, micaceous, and very fine-grained sandstone, light-gray, partly very thin-laminated; one thin bed ferruginous, fossiliferous with *Syringothyris* sp., lowspired gastropods, crinoid columnals, and bryozoans	16.2
	56	Argillaceous ferruginous sandstone, brownish reddish-purple, very fine-grained with subrounded coarse to very coarse grains scattered, very fine muscovite, friable	2.0
	55	Ferruginous sandstone, fine- to very coarse-grained, conglomeratic in upper part with subrounded pebbles to 10 mm, some siltstone and feldspar, grayish-reddish-purple	5.5
	54	Partly covered. Shale, yellowish-gray, very fine muscovite, carbonaceous, with minor interbedded siltstone, very thin-bedded	12.5
	53	Sandstone, feldspathic, medium- to very coarse-grained, subangular, sparsely carbonaceous, thick-bedded; one bed ferruginous, reddish-brown	8.0
	52	Very silty shale, light-gray, micaceous, carbonaceous, blocky; with interbeds of arkosic sandstone, very fine-grained, angular, dense, light-gray	26.2
		Broad Ford Sandstone Member (217.3 feet)	
	51	Interbedded sandstone (40%) and shale (60%) with thin- to medium-bedded sandstone layers spaced at 0.5- to 1.5-foot intervals. Sandstone, feldspathic, medium- to very coarse-grained, subangular, very light-gray, fair porosity,	

	UNIT NO.		THICKNESS (FEET)
		some sandstone very fine-grained, light-gray, micaceous. Silty to sandy shale, light-gray, very micaceous, some feldspar	61.0
	50	Silty shale, medium-gray, medium to coarse muscovite, slightly carbonaceous with 25% interbeds of quartzitic sandstone, very fine-grained, angular, thin- to medium-bedded. Normal fault with 1.0 foot displacement near top of unit. Rare *Chonetes* sp. imprint	44.7
	49	Arkosic sandstone, quartzitic, very fine-grained, angular, light-gray	1.2
	48	Sandy, arkosic shale, medium-gray, very micaceous, sparsely carbonaceous, varies in thickness 3.7 to 3.0 feet; contains two very thin beds of sandstone, very fine-grained, quartzitic, grayish-brown, cross-laminated	3.0
	47	Arkosic sandstone, quartzitic, fine-grained, angular, light-gray, with 0.2-foot-thick shale bed in middle, sandy, arkosic, medium-gray, very carbonaceous with plant stem fragments, micaceous	8.0
	46	Interbedded sandstone and shale (25%). Sandstone, arkosic, argillaceous in part, quartzitic in part, fine-grained, medium- to light-gray, carbonaceous, medium to coarse muscovite, very thin- to thick-bedded, cross-bedded, dips 18° S15°W, ripple-marked, crest to crest 5.1 inches, trough trend N85°W. Silty shale, medium-gray, micaceous, slightly carbonaceous, hackly. Clay-pebble conglomerate on one bedding plane near top	28.3
	45	Sandstone, very fine- to fine-grained, angular, dense, light-gray with some medium-light-brownish-gray in lower 15 feet, medium to very coarse muscovite, few carbonaceous fragments, clay pebbles on some bedding, thin- to thick-bedded, even, flat bedding; some arkosic beds; 2.0-foot-thick fractured zone 15.0 feet above base. Few silty shale partings in lower 15.0 feet	62.3
	44	Interbedded sandstone, fine-grained, angular, dense, light-gray, micaceous, very carbonaceous layers, even medium-bedded, and very silty shale, mottled gray and brownish-gray, micaceous	8.8
		Ceres Member (63.4 feet)	
7.5	43	Silty shale, partly sandy, medium-gray to olive-gray, very micaceous, fine to very coarse flakes, layers very carbonaceous, subfissile to partly pencil; minor, very thin-bedded sandstone, very fine- to fine-grained, slightly arkosic, dense, light gray, few carbonized plant stems. Normal fault with about 20.0-foot displacement about 40.0 feet below unit top	63.4
		Big Stone Gap Shale Member (20.6 feet) (Exposed on hillslope about 300 yards east of highway.)	
7.55	42	Silty shale and clay shale, dark-gray to medium-dark-gray, brittle, fissile	20.6
		Cloyd Conglomerate Member (22.0 feet) (Exposed on hillslopes off highway.)	
	41	Sandstone, fine- to very fine-grained with lensing beds to 5.0-foot-thick quartz-pebble conglomerate, rounded pebbles to 20 mm., dense, clean, quartzitic, medium- to thick-bedded	22.0
		Devonian:	
		"Chemung" Formation (147.6 feet) (Exposed on hillslopes off highway).	
	40	Covered interval. Some fossiliferous siltstone float with *Camarotoechia* sp. brachiopod imprints	103.0
	39	Siltstone, medium-gray, very micaceous, few carbonaceous plant fragments, very thin- to thin-bedded, thinly laminated	5.6
	38	Partly covered. Siltstone, very fine muscovite and slightly silty shale	28.0
	37	Argillaceous siltstone, light-olive-gray, bedding surfaces brownish-gray, very fine muscovite, very thin- to medium-bedded, some plant fragments	11.0
		Brallier Formation (679 feet ±, top and base of formation covered.)	
	36	Covered interval	42.8
7.7	35	Slightly silty shale, light-olive-gray, very fine muscovite, very fine carbonaceous plant fragments; few siltstone beds, light-olive-gray, very fine muscovite, some disc-shaped specimens of *Sporangites* sp., very thin-bedded	28.6
	34	Shale, greenish-gray to gray-brown weathers to light-yellow, hackly; partly exposed along highway and in creek bed east of highway	607.6
		Millboro Shale (684 ± feet: top and base of formation covered)	
	33	Mostly covered, except for two small outcrops of shale in creek east of highway dark-gray, hackly to fissile, with very fine mica	684
		Huntersville Formation (83.9 ± feet: top and base of formation covered.)	
8.4	32	Chert, light-gray to white, blocky, medium-bedded, fossiliferous; poorly exposed in creek, roadcut excavated in 1969 exposed chert and sandstone containing eight brachiopod and one gastropod species	10
	31	Covered: probably shale and sandstone (may include Oriskany and Keefer sandstones)	48.9
	30	Conglomeratic sandstone, light-gray to purplish-brown, medium- to very coarse-grained with rounded, frosted quartz pebbles up to 10 mm diameter massive- to thick-bedded	25

	UNIT NO.		THICKNESS (FEET)
		Silurian:	
		Rose Hill Formation (147.5 ±feet)	
	29	Siltstone and sandstone, dark-purplish-brown fine-grained, dense, medium- to thick-bedded	13
	28	Silty shale, reddish-brown and light-greenish-gray	25
	27	Siltstone, dark-purplish-brown, medium-bedded	2
	26	Interbedded siltstone, thin-bedded, and shale, light-brown, with polished bedding surfaces	22
	25	Sandstone, gray to dark-gray, fine-grained, medium- to thick-bedded: grades upward to silty sandstone	19
	24	Clay shale, light-gray, fissile	2
	23	Clay shale, light-gray, fissile, with thin interbeds of siltstone	12
	22	Siltstone, gray, dense, thick- to thin-bedded	10
	21	Ferruginous shale, mottled brown, with oolitic iron structures	0.5
	20	Siltstone, light-gray, with some red-brown tubular worm borings perpendicular to bedding, with interbedded ferruginous shale partings	8
	19	Shaly siltstone, dark-purplish-brown, weathers mottled, medium-bedded	5
	18	Siltstone, iron-stained brown to purple, thick-bedded	17
	17	Shaly siltstone, mostly covered	12
		Tuscarora Sandstone (196.1 ±feet)	
8.5	16	Sandstone, light-gray, quartzitic, thick-bedded	9
	15	Siltstone, light-purplish-gray, thick-bedded	4
	14	Silty shale, gray	0.5
	13	Sandstone, light-gray, quartzitic, thick-bedded	25
	12	Shale, light-gray, slightly silty with some gray, thin-bedded siltstone	3
	11	Sandstone, light-gray, quartzitic, medium- to thin-bedded	40
	10	Sandstone, gray, fine-grained, dense, siliceous, thin- to medium-bedded with thin argillaceous beds at top	11
	9	Mostly covered: two beds of medium-bedded quartzitic sandstone crop out; dip 22° SE	42.4
	8	Quartzitic sandstone, light-gray, massive	10
	7	Silty shale, light-gray, with siltstone lense in middle	1.2
	6	Quartzitic sandstone, light-brown, fine- to medium-grained, massive-bedding	24
	5	Quartzitic sandstone, light-brown, fine- to medium-grained, massive-bedding, with planar and festoon cross-bedding; depositional dip computed to be 3°-5° N47°W	2
	4	Sandstone light-brown with reddish-to yellowish-brown iron-stained laminae, fine- to medium-grained, massive-bedded, planar cross-bedding: ripple-marked surfaces with crest line trend S° 40° E; quartzitic	24
		Ordovician:	
		Juniata Formation (26 ±feet)	
	3	Covered: probably siltstone	9
	2	Siltstone, maroon and gray, thin- to medium-bedded, with worm-boring-like markings	5
	1	Interbedded silty shale, hackly, and siltstone, purplish-red, grades upward into mottled greenish- and purplish-gray, knobby, thin- to medium-bedded.	12
8.9		Highway cross-over to John Douglas Memorial Wayside.	

END OF ROAD LOG.

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SCHEDULED MEETINGS

October 23-25, Carolina Geological Society, Gaffney, South Carolina (Carolina Geological Society, Box 6665, College Station, Duke University, Durham, NC 27708).

November 2-5, Geological Society of America, Cincinnati, Ohio (Lois J. Campbell, Dept. of Geology, University of Kentucky, Lexington, KY 40506).

November 5-6, Virginia Association for Environmental Education, Skyland, Shenandoah National Park (Tim Tigner, Division of Forestry, Box 3758, Charlottesville, VA 22903).

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NEW PUBLICATIONS

PUBLICATION 28

Lineament and Fracture Trace Analysis and Its Application to Oil Exploration in Lee County, Virginia by Thomas M. Gathright, II, has just been published by the Division as Publication 28. Linear traces from aerial photography and LANDSAT imagery are used to evaluate oil producing areas. The methodology of interpreting these linear traces and positioning them on geographic bases is discussed in the publication. The fracture traces, related by means of Cartesian Azimuth distributions and rose diagrams, are shown on 21 separate topographic maps. These maps also show the location of 126 test wells in the county. The publication also gives information on oil bearing strata, their structural position, and their relation to linear traces.

Publication 28 is available from the Division for $3.84 postpaid.

PUBLICATION 30

The Geology of Hanover Academy Quadrangle, Virginia is available for $4.62 postpaid. The map shows the distribution of rock units on a topographic map base with interpretive cross-sections. Present or historical economic resources of the area include gravel, crushed stone, dimension stone, iron, mica, coal, and zircon. The publication also discusses soil types, excavation problems of the area; and water possibilities.

PUBLICATION 31

The Geology of Glen Allen Quadrangle not only describes the geology of the area but also lists geologic and economic factors affecting land modification of the rock units. Interpretive cross-sections are also included with the map. The text portion of the publication discusses the availability of materials suitable for producing crushed stone, bricks, and coal. The usefulness of the rock units for solid and liquid waste disposal, building and road construction, and water supply are also indicated. Publication 31 is available from the Division for $4.62 postpaid.

PUBLICATION 32

Publication 32, High-silica Resources in Augusta, Bath, Highland, and Rockbridge Counties, Virginia is available for $3.06 postpaid. Physical descriptions, sieve analyses, and chemical test data are presented so that the commercial potential of high-silica resources in these counties can be evaluated.

Most of the area's silica resources are contained within the Antietam and Tuscarora formations and the Keefer and Ridgeley sandstones. A total of 249 sandstone and quartzite localities were examined. Composite samples from each of the principal resource units were analyzed for silica content in a raw or unbeneficiated condition; silica content of the units ranges from 97.2 to 99.1 percent. The percentage of silica in beneficiated samples ranges from 98.9 to 99.5 percent for the same samples. Grain-size distribution, average grain size, and degree of sorting for most samples are shown by histograms and cumulative frequency curves. The study is similar to an earlier publication on the silica resources of five northwestern Virginia counties.

VIRGINIA MINERALS

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GAS PLAYS IN OVERTHRUST BELTS: ACTIVITY IN VIRGINIA IS INCREASING

S. O. Bird

Vast blocks of onshore land are being leased in Virginia and other Appalachian states as major oil and gas companies begin what promises to be a pervasive and intensive exploration program in the Eastern Overthrust Belt. Origins of this activity and some of the obstacles to its rapid culmination in drilling programs from the Piedmont to the Plateau are discussed in this article.

Feast: Conservation of motor gasoline and other oil products began in earnest in 1979 largely as a result of the sharp increase in the price of petroleum, and helped produce a world-wide oil "glut." Several countries cut their crude oil prices in 1981 and prices were down in the world market place during most of 1981. Americans, who use a third or more (37 percent in 1978) of the oil consumed each year by the world's free countries, played a major role in these developments. Following the oil embargo year of 1974, use of motor gasoline increased until 1979 (Table 1A) when it dropped slightly, and in 1980 Americans cut their consumption of motor gasoline by 164 million barrels — a decrease of about 6 percent from the 1979 level.

This decrease is reflected in a 20 percent drop in total crude oil imports from 1979 to 1980.

These imports fell an additional 20 percent in 1981. The downward trends in use are large enough to bring about large-scale revisions in government predictions of future energy supplies. The total 1990 energy supply that was predicted in 1978 is some 15 percent higher than that predicted two years later (Table 1B). New predictions for 1990 will undoubtedly be lower on the force of recent use curtailment and of probable future increases in prices. Many are predicting that the oil glut will end by 1984, an event that would bring an increase in today's relatively stable prices and consequent increase in conservation.

And Famine: The U. S. plans to cut oil imports substantially by 1990. When compared with the 1978 predicted need for 1990 this decrease would produce a sizeable shortfall in supply which would have to be made up from other sources. And though high prices and curtailed use continue to limit imports and to produce downward revisions in predictions, it seems certain that unless there are large new fuel discoveries or breakthrough technological developments, the U.S. will be oil and gas poor by the turn of the century. The reasons are that growth in population and industry will seek an increasing production from a dwindling reserve.

The U. S. is currently producing more than 5 times as much oil as any other noncommunist bloc nation, with the exception of Saudi Arabia, a country which produced oil during most of 1980 and 1981 at its all time high in an effort to keep pace with the demand for its oil, which was until recently priced below other OPEC oil. Production for the U. S. is now about 8.6 million barrels/day; an equal or higher production rate is predicted to continue until the year 2000. Exploration and revision of estimates of reserves in old fields have brought a near balance between reserve depletion and reserve renewal. This ratio was nearly 2 to 1 in 1979 (7 billion barrels per year depletion against 3.8 billion

Table 1A. U.S. motor gasoline use from 1973-1981. Data from Energy Information Administration (1981A).

Thousands of barrels/day					
Year	Used	Imported	Year	Used	Imported
1973	6674	134	1978	7412	190
1974	6537	204	1979	7034	181
1975	6675	184	1980	6579	140
1976	6978	131	1981	6583	161
1977	7171	217			

Table 1B. Energy supply and 1990 predictions. Values are in quadrillion Btu's. Data from Energy Information Administration (1981B).

	1978	1979	1980	1990[a]	1990[b]
Oil					
Domestic	20.7	20.4	20.5	23.1	19.7
Imported	17.1	17.9	14.4	17.0[c]	11.1
Gas					
Domestic	19.5	20.1	19.7	17.4	16.0
Imported	0.9	1.3	1.0	2.0	1.0
Coal	15.0	17.7	18.9	31.2	30.3
Nuclear	3.0	2.8	2.7	9.4	8.0
Other	3.0	3.0	3.0	3.5	3.6
	79.2	83.2	80.2	103.6	89.7

[a] 1978 "mid-price" estimate

[b] 1980 "mid-price" estimate

[c] If oil imports restricted to 8 quads as planned, a deficit in supply of 9 quads was forecasted by the 1978 prediction.

1 quadrillion Btu = 1 quad = 172 million barrels of oil = 969 billion cubic feet of natural gas = gasoline to drive 10 million cars/year.

1 barrel oil = 42 gallons = 5.63×10^3 cubic feet of natural gas

barrels per year renewal), and though depletion and renewal are now nearly equal, an imbalance toward depletion must certainly soon come about. At present the renewal rate is about 52 barrels of oil (or an equivalent amount of gas, about 300 thousand cubic feet) produced for each foot of rock drilled in the U.S. This may seem to be a substantial amount of oil and gas for the drilling, but it is only about one-sixth the value obtained in the late 1940's.

And yet the immediate best prospect for supplying the special energy needs of the U. S. now being met by oil and gas is new discoveries of domestic oil and gas. Large new oil and gas fields are being discovered in the Rocky Mountains (Western Overthrust Belt) and large gas fields are being found in the Gulf Coast (the Tuscaloosa Trend of Louisiana and Texas), and there are significant new finds in the Valley and Ridge of the Appalachians. These strikes give hope that future discoveries will yield sufficient gas to stem imports and see the U. S. through the time from now until a new technology closes the door on the need for fuel imports. (Most of the statistical data presented in this section are from sources listed under *Oil and Gas Journal* and *Energy Information Administration* entries in "references.")

GAS AND OIL IN VIRGINIA: THE BEGINNING

Some 20 years after completion of the world's first oil well in 1859 at Titusville, Pennsylvania, drilling began in Virginia with an exploratory well in Wise County, but there was no significant oil or gas production in Virginia until 1931, when the Early Grove gas field in Scott and Washington counties was drilled following a geologic study of the area by Charles Butts (1927). Gas was produced at the Early Grove field, which is in the Valley and Ridge province, from 1931 to 1958. Production was mainly from sand lenses in the Little Valley limestone (Mississippian). Today, most gas production in Virginia is from the coalfield gas fields in the Appalachian Plateau province; production from Dickenson County currently exceeds the combined production of all other counties in the State. Production in Plateau fields is mainly from the Greenbrier Limestone (an interval including rocks equivalent in age to the Little Valley limestone), from sandstones higher and lower in the Mississippian section, and from Devonian shales (Table 2); these fields were discovered between 1948 and 1961 (Le Van, 1981).

There is currently renewed interest in the Early Grove field area and in other regions of the Valley and Ridge province. Highlander Resources Company hit one and probably two commercial gas zones in a well drilled near the center of the Early Grove field just west of the Washington County line. The deeper (about 3400 feet) of the two gas zones is the Little Valley Formation. Drilling is to continue to the Berea which is near the base of the Mississippian section at 5200 feet, according to Charles Bartlett, consultant geologist for Highlander Resources. Two old wells in the Bergton field, Rockingham County, have recently been put back into production by Scott Enterprises and two new wells in the same county were brought into production by Merrill Natural Resources of Chesterfield, Virginia in 1981 (Figure 1). Pipelines for these four producing wells have been completed.

Table 2. Highly generalized stratigraphic column for Precambrian to Lower Mesozoic rocks in Virginia.

Age	Rock Unit	Remarks
Triassic	Terrigenous clastic units, coal beds and intrusive mafic rocks	Sedimentary rocks are in grabens and half grabens formed in the Piedmont. **Area undergoing active exploration for oil and gas.**
Pennsylvanian	Cyclic, largely continental, sequences of sandstone, mudstone, coal	Youngest Paleozoic beds in Va., which are at the surface in S.W. part of State.
Mississippian	Various terrigenous clastic units	
	Greenbrier Limestone: Several limestones	**Major gas producing beds in S. W. part of Va.**
	Greenbrier Limestone: Little Valley Formation	
	MacCrady Shale	*Decollement zone*
	Price/Pocono sandstone and conglomerate; includes Berea Sandstone in subsurface	Erosion-resistant caprock of Allegheny Front at western margin of Valley and Ridge province. **Berea is reservoir rock.**
Devonian	Chattanooga Shale	Black shale and **major source beds for Appalachian hydrocarbons. A reservoir rock.**
	Oriskany Sandstone; Helderberg-age limestones and sandstones	**Important reservoir rock in W. Va. and Pa.**
Silurian	Salina Group limestones; salt beds in W. Va. and Pa.	*Major decollement zone* in Plateau province of W. Va. and Pa.
	Various clastics, some continental. Tuscarora Sandstone	**Important reservoir rock in W. Va. and Pa. and drill-bit target in Va.** *Ramp zone.*
Ordovician	Terrigenous clastics of Juniata/ Sequatchie formations Martinsburg Fm.	*Major decollement zone*
	Trenton Limestone	**Main reservoir rock in Rose Hill and Ben Hur oil fields**
	Various mudrocks and limestones	*Major ramp zone*
Cambrian	Beekmantown and Knox group carbonate rocks	*Major decollement zone*
	Conesauga Group and Rome Formation Shady Dolomite Chilhowee Group	*Major decollement zone*
Precambrian	Catoctin greenstone and other formations and rock types	Basement complex

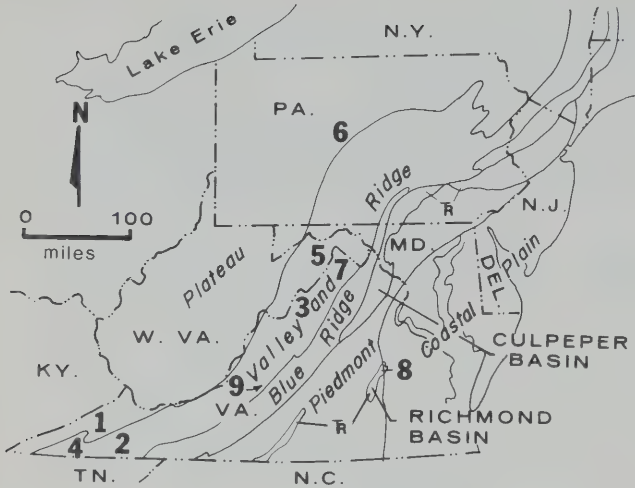

Figure 1. Oil and gas fields in Virginia, Appalachian physiographic provinces, and general areas of newly discovered gas fields and recently drilled wells. (1) coalfield gas fields, (2) Early Grove gas field, (3) Bergton gas field (Rockingham County), (4) Rose Hill and Ben Hur oil fields. Areas of newly discovered gas fields are in Mineral County, W. Va. (5) and Centre County, Pa. (6). New exploratory wells in Virginia mentioned in text are ones in Scott (2), Rockingham (3), Lee (4), Frederick (7), Chesterfield (8) and Botetourt (9) counties.

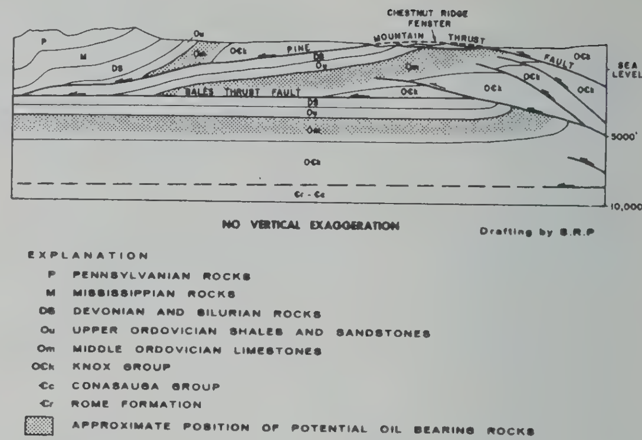

Figure 2. Generalized structure section across Rose Hill oil field (from Gathright, 1981), which lies in the area of the Chestnut Ridge fenster. The base of the Cumberland thrust sheet here is the Pine Mountain fault.

The first commercial oil production in Virginia began in 1942, when the Rose Hill field in Lee County was brought in. Later, in 1963, oil was discovered in the Ben Hur field, which is also in Lee County (Figure 1). These oil fields are the only ones in Virginia, and, more strikingly, they are virtually the only oil fields in the Valley and Ridge province. The two fields are mainly located in fensters eroded through the Cumberland thrust sheet (Figure 2). The Trenton Formation (Upper Ordovician) is the chief reservoir rock. Production from the two fields totalled about 9500 barrels for 1980. Production from beneath a major thrust sheet is something of a geologic novelty, but future exploration in the Appalachians will probably penetrate many such areas, as is discussed next.

GENERAL ANATOMY OF AN OVERTHRUST BELT

Thrust faults give silent testimony of dramatic change at the earth's surface, where the faults are recognized by the juxtaposition of rocks of unlike age and, commonly, of unlike lithology. Some of these thrust sheets are on a truly grand scale: two named for towns in Virginia, the Saltville and Pulaski thrust faults, and one named for the Blue Ridge Mountains extend across several states and have displacements measured in miles.

The gigantic size of such faults is one of their features making it difficult to account for their origin. If the faults originated by horizontal compressive forces, how were the forces transmitted through relatively weak rock (weak at such scales)? Or, alternatively, did the faults arise as a result of great masses of rock sliding down a gentle incline on the force of their own weight and then piling up at the toe of the slide as age and displacement relationships among the faults seem to require (Milici, 1975)? Thus debate has centered on the origin and transmission of the forces causing rupture and displacement, and on length of displacement, place of origin or "root zone," and angle of dip of thrust sheets. Geologists aligned themselves on two sides of the fault-origin question: were the thrusts deep seated and displaced along planes with high angles of dip ("thick-skinned model") or were they shallow seated with low angles of dip ("thin-skinned model)? Evidence in support of the thin-skinned position included field observations that regionally related faults contain identical beds in the leading edge of their hanging walls—evidence suggesting that the faults arose repeatly from a common depth. Many of the concepts on fault mechanics arose from studies on Appalachain geology. Because crystalline rocks of the basement are not included on the fault surfaces west of the Blue Ridge, it was assumed that the faults to the west in the Appalachians were shallow seated. In contrast, two main observations comprised evidence that seemed to support a deep-seated origin of thrusts and associated structures: thicknesses of some sedimentary units in-

crease toward centers of certain synclines (which supported the idea that folds grow through long intervals of geologic time), and depth to the crystalline rocks forming the basement is somewhat variable (which seemed to show that some folds extend to basement). From these observations it was inferred that thrust faults were deep seated and that they generally post-dated folds.

Deep drilling first and geophysical data (mainly seismic) second, pretty well put the matter to rest in the Appalachians, and elsewhere, for thrust faults were shown by drilling in West Virginia, Virginia and Pennsylvania to underlie folded beds similar to those in the Valley and Ridge province and to overlie flat-lying beds typical of the Plateau province (Gwinn, 1964). Seismic data have recently been used to illustrate that these relationships extend throughout the Appalachians (Milici and others, 1979; Cook and others, 1979; and Harris and Bayer, 1979), and in other mountain chains, throughout the world.

A major piece of the puzzle explaining the forces producing thrust faults was supplied by Hubbard and Ruby (1959) and Ruby and Hubbard (1959), who presented compelling evidence that these faults could originate along impervious and incompetent beds such as shales and salt beds on gentle slopes under the force of the weight of the rocks above them. This was an especially welcome idea because it was such impervious and incompetent rocks that had long been known from field mapping to be on the hanging walls of thrust faults. And it was these beds that were later shown by drilling to lie beneath areas of deformed rock and above areas of undeformed rock. The gravity slide theory did not require rocks to transmit deforming forces to the area of rupture.

As these ideas of the origin of thrust faults became part of the thinking of many geologists, the whole concept of how the folds of mountain chains such as the Appalachians are formed began to undergo profound change. During this time of revolution in geologic thinking, the ideas of Rich (1934), who presaged these new concepts, were "rediscovered." One major idea of the new concepts is that rootless folds form as a result of displacement on thrust faults, indeed the idea has become one of the empirical "rules" of thrust belt structural geology. This and other rules have been summarized by Royse and others (1975); Harris and Milici (1977); Allmendinger (1981); and others. Some of the relationships are shown in Figure 3; these include the idea that many folds in thrust belts are produced by faults, that synclines are passively formed as a result of displacement that forms anticlines adjacent to them, that structures above and below decollements are unequal to each other, and that decollements are in incompetent beds and that ramps are in competent ones. The importance of these relationships to exploration for oil and gas will be evident in the following discussions. One important consequence of the idea that anticlines (the major structural oil and gas trap) are produced by faults is that they do not extend below the decollement forming them.

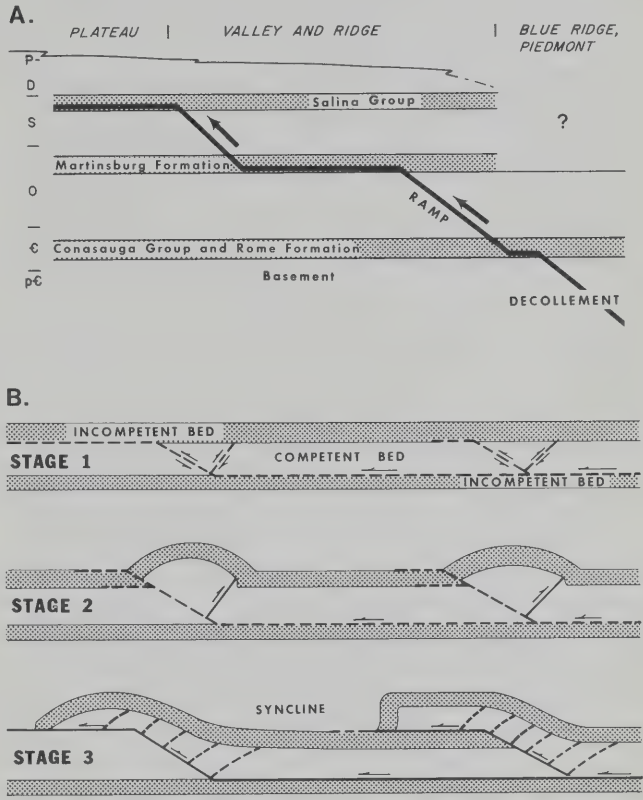

Figure 3. Simplified, conceptual diagrams of decollements and attendant structures. A. "Major Appalachian decollement" lies within incompetent and impervious rocks such as shales and salt beds, and "ramps" across incompetent beds such as sandstones and limestones; the thrust lies at successively higher stratigraphic zones in the direction of motion. Stratigraphic symbols are P, Permian; D, Devonian; S, Silurian; O, Ordovician; €, Cambrian; p€, Precambrian. The Upper Devonian to Lower Mississippian interval also is a major fault zone. B. Anticlinal and synclinal structures formed by thrusting. Anticlines here result from thickening of the incompetent bed and by growth of reverse faults, which originate near the toe of the ramp zone and migrate up it (Morse, 1977). The resulting convex-upward form extends to higher strata. Synclines are passively formed between anticline, according to these ideas. Continued movement along the decollement generally results in complex arrangement of rocks, — see, for example, Milici (1962). The E-W distance in Figure 3B is a few tens of miles. See Table 2 for notes on rock units.

OVERTHRUST BELTS AND HYDROCARBONS

The West: Oil and gas prospects in overthrust belts have not long been viewed with enthusiasm, for though there has been sizeable hydrocarbon production beginning in the 1920's (and beginning to boom in the 1950's) from the Rocky Mountain foothills in Alberta, an area which forms a tiny part of the Western Overthrust Belt, extensive exploration in geologic similar areas in Montana, Wyoming and Utah failed in discovery of significant hydrocarbon resources until recently. The Western Overthrust Belt extends from Alaska into Mexico. Discovery of oil and gas in the U. S. part of the Belt began in the 1950's, but it was American Quasar's 1975 discovery of the Pineview oil field in Utah and Amoco Production Company's 1976 strike some 40 miles to the north at Ryckman Creek, Wyoming (Figure 4), that spurred the feverish play now in progress in the Western Overthrust Belt of the U. S. Discovery in the U. S. has so far been mainly in the Utah-Wyoming segment of the Belt; in five years (1975-1980) the 50-mile-long segment yielded twelve commercial fields in Utah and Wyoming (Figure 4). Five of the fields are defined as giant fields, ones with recoverable reserves of at least 300 billion cubic feet of gas or 50 million barrels of oil. Most wells in the region are more than 13,000 feet deep. Eleven of the twelve fields are in anticlines, which presumably developed during thrusting in the hanging walls (upper sheets) of two (the Absaroka and Tunp) of the six major thrust faults of the Western Overthrust Belt (Anschutz, 1980). There are at least seven productive formations in the anticlines and this gives prospectors hopes of discovering huge fields. Reservoirs in the region are Mesozoic and Paleozoic rocks of the upper thrust sheet which are juxtaposed with source rocks of Cretaceous age in the subthrust sheet; the Nugget Sandstone (Jurassic) is a prime target of the drill bit. As we shall see, there are several reasons why prospectors are not so hopeful for giant fields in the Eastern Overthrust Belt.

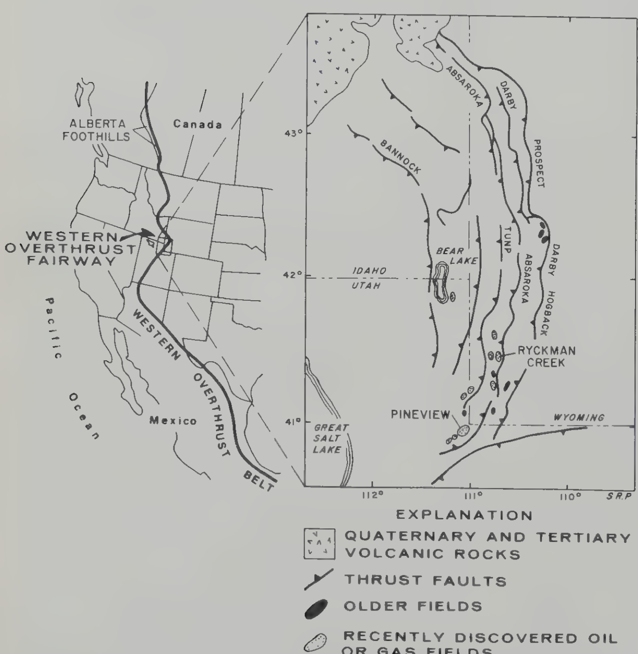

Figure 4. The Western Overthrust Belt (after Anschutz, 1980).

Exploration in the Western Overthrust Belt has recently been extended to the far southeastern reaches of the U. S. part of the Belt, where drilling is underway in Arizona and New Mexico. Some geologists are predicting that reserves in the Belt will eclipse those at Alaska's Prudhoe Bay, which holds 9.5 billion barrels of oil and 29 trillion cubic feet of natural gas (McCaslin, 1980A). Significant gas production from Alaska will not begin until pipelines to the U. S. are completed.

The East: It was largely discoveries in the Western Overthrust Belt, and the general similarity of the geology of this Belt to what is now being called the Eastern Overthrust Belt, that stimulated the broad exploration efforts underway in the Appalachians. The factors which led to discoveries of hydrocarbons in the West (economic incentives, improved seismic technology as well as more abundant data, and a new understanding of geologic structures) are at work in the promotion of exploration in the East. Virtually all of the oil and most of the gas produced in the Appalachians has come from the Plateau province, an area once thought to have undergone little tectonic upheaval. Data from drilling projects, seismic reflection studies and geologic mapping show that all or much of the Plateau province in Pennsylvania, West Virginia, and Virginia lie above a decollement in Upper Silurian salt beds (Gwinn, 1964; Milici, 1980) or in shales of equivalent or somewhat younger age. Thus the gas and oil produced from the Plateau province of these states are from structures lying above a major decollement.

The part of the Eastern Overthrust Belt (Figure 5) of prime interest for oil and gas exploration extends a distance of about 1100 miles from New Jersey to Alabama. It is probable that most oil and gas exploration and production in the Appalachians will contine to be from the Plateau province, which in 1976, the latest year for which state data are available, produced about one and one-half percent of the Nation's natural gas, but there is mounting interest in Valley and Ridge and even in Blue Ridge and Piedmont areas. Commercial quantities of gas may exist in association with Mississippian-age coal beds in the Valley and Ridge province. A test well to be drilled in 1982 by the Virginia Division of Mineral Resources in Montgomery County

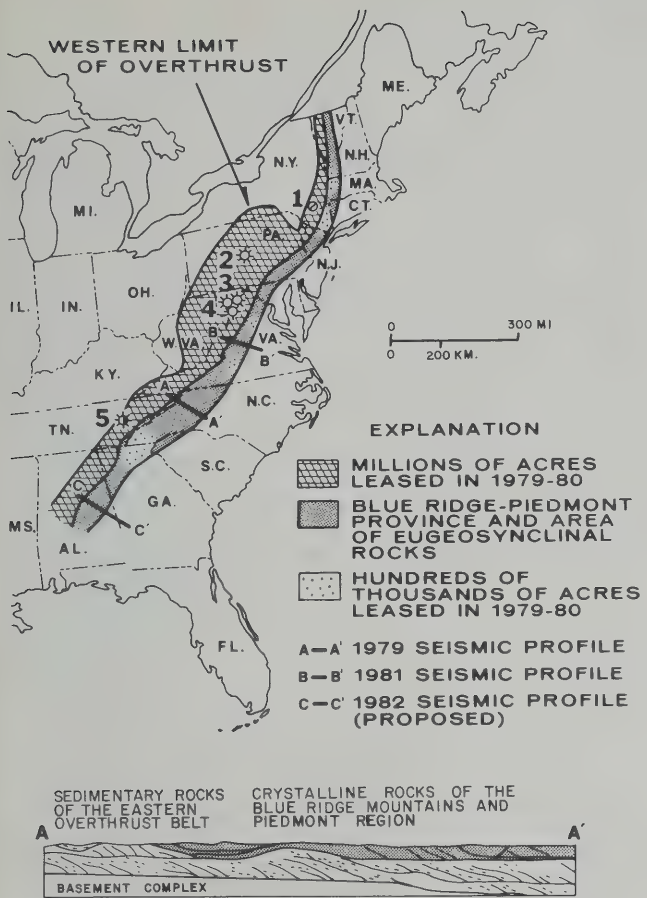

Figure 5. The Eastern Overthrust Belt (after Crow, 1981). Wells and fields indicated by numbers are (1) ARCO 1 Susi; (2) Amoco's Devils Elbow fields; (3) Columbia's Mineral County wells; (4) Exxon 1 Bean.

near Blacksburg, Virginia has been funded by a grant from the Department of Energy. The hole is planned for a depth of 3000 feet; it will penetrate the Pulaski thrust sheet and coal-bearing Mississippian strata beneath the sheet.

PROSPECTING IN VIRGINIA: THE FUTURE

A small part of Virginia lies within the prime oil and gas area of the Appalachians, the Plateau province, and this is the area of greatest gas production in Virginia (Figure 6). There is currently small production from the Valley and Ridge of Virginia, but it is in this area that exploration is likely to be most intense in the State.

Before proceeding with notes on these prospects, it is well to look at some negative factors bearing on exploration in Virginia and in the Appalachians in general.

Economic factors:

- U. S. drilling and completion costs in 1980 were up 41.2 percent from 1979; the average cost of drilling per foot in 1980 was nearly $68, up by almost $10 from the 1979 value (McCaslin, 1981). Drilling costs in the Appalachians are generally high because of the common occurrence of well-indurated sandstones that are difficult to drill through, the need to bring in rigs from outside the area, and other factors including those resulting from the effects of rugged terrain and dense vegetation; an 8,000-foot well in the Appalachians costs the same as a 15,000-foot well in Oklahoma.
- Many wells in the Valley and Ridge of Virginia and elsewhere in the Appalachians may need to be drilled to depths of 11,000 to 12,000 feet; the current cost of such wells is expensive at 2½ to 3½ million dollars (Crow, 1981).
- Many productive wells will not be so deep as 15,000 feet and gas from them therefore will not qualify for price degregulation provided by Section 107 of the 1978 Natural Gas Policy Act. The Federal Energy Regulation Commission can and does deregulate gas prices from "tight" rocks, ones with low porosity, on an *ad hoc* basis, but resulting prices are not nearly so attractive as those from rocks below 15,000 feet. Deregulation from other high cost sources and general deregulation will not likely soon take place (Jennrich*, 1981), and, accordingly, high production costs and risks in the Appalachians will not soon be matched by high sales prices.
- Gas can be obtained from Canada, and will likely soon be available from the Western Overthrust Belt in Mexico, that is cheaper than domestic gas from deep wells.
- More than 300 dry wells were drilled in the U. S. part of the Western Overthrust Belt before there was a significant discovery.

Geologic factors:

- Intergranular porosity is low in Valley and Ridge rocks and production may depend heavily on the number and spacing of fractures in reservoir rocks, both of which are generally unknown prior to drilling the rocks.

*In a more recent article, Jennrich (1981b) states that a probable federal government need for additional revenue may result in gas deregulation so that a windfall tax can be levied on it.

- It is likely that gas and not oil will represent hydrocarbons in the Valley and Ridge, for conodont color alteration indices indicate that rocks in the province were cooked at temperatures and pressures generally too high (hydrocarbons are too mature) for oil to be preserved (see Harris and Milici 1977).

In summary, then, it can be said that in spite of similarities between structures of the Appalachian and Rocky Mountains, prospects in Virginia, as well as in other Valley and Ridge areas of the Appalachians, are not quite so bright as in the Rockies. "Deficiencies" in the Valley and Ridge include the relative antiquity of the rocks and a related high maturity of hydrocarbons in them; tight cementation of potential reservoir rocks and consequent loss of intergranular porosity in these rocks; a relatively small number of source beds, which are fault-omitted in some places otherwise suitable as prospects; and a relatively small number of reservoir beds, which are generally widely, rather than closely, vertically spaced. In addition, exploration is more difficult in the East than in the West because rocks with high seismic wave velocities lie near the surface in the East (limestones and indurated sandstones in the Valley and Ridge provinces, and a variety of metamorphosed rocks in the Blue Ridge — Piedmont provinces). Where such rocks overlie ones of lower velocity, seismic waves are sent deeper into the earth rather than being reflected back to the surface, and reflection records are correspondingly more difficult to interpret with precision. Differences between East and West in terrain and vegetation are also in favor of profitable exploration in the West.

Impetus: Against these negative factors is one fact: six new gas wells in and just west of the Valley and Ridge province give promise of big strikes and fuel the hope of discovery in the Eastern Overthrust Belt just as the Pineview strike did in its western counterpart. Three of the six wells (Figure 6), which were all wildcats, were developed by Amoco, perhaps the most active exploration company in the Western Overthrust Belt and a major landholder in the East. The three Amoco wells were completed in 1977 in Centre County, Pennsylvania; total natural gas flow is 9.5 million cubic feet per day (MMcfd). Two of the wells are in the Tuscarora (Silurian) and one is in the Oriskany (Devonian). The other three wells were drilled by Columbia Gas Transmission Corporation in Mineral County, West Virginia. Gas flow rate in two of these wells, completed in 1978 and 1980 in the Oriskany, totals 17.8 MMcfd (Crow, 1981). The giant of the six wells was completed by Columbia in 1981 in the Tuscarora; gas flow rate is 88 MMcfd, according to Mr. B. T. Fulmer, State Oil and Gas Inspector. (Stratigraphy is shown in Table 2.)

On the strength of these discoveries, leasing activities in the Appalachians has become hectic as companies struggle to fill in their holdings. At present, more than 3 million acres in Virginia have been leased for oil and gas exploration.

To Action: Several exploration and development wells have been completed in the Valley and Ridge of Virginia. Mr. Fulmer reported that two new field wildcats recently completed by Amoco, one in Frederick County, and one in Rockingham County, were dry holes. The target in each well was the Tuscarora Sandstone. Four wells, three development and one new field wildcat, were drilled in Rockingham County by Merrill Natural Resources. Two development wells were completed in the Oriskany Sandstone; the wildcat and one development well were dry holes. Farther south, near Gaylor in Botetourt County, Columbia Gas and Transmission Company has just finished drilling a dry hole below the Tuscarora, the original "target" in this stratigraphic test well.

Highlander Resources drilled 7140 feet through a thick Mississippian section in reaching the Berea Sandstone (Mississippian) in the Greendale syncline in Washington County. There was a gas flare, flow of gas from the well, when drilling entered the Little Valley Formation, and there was a gas show in the overlying Fido Sandstone. Work is now underway to determine if there are commercial quantities of gas in the well.

In 1981, 66 permits for drilling oil and gas wells in Virginia were issued—a number nearly one and one-half times as large as the total number permitted in the State in 1980. Fifty-three oil and gas wells were drilled in 1981 and 22 were completed as producers; the corresponding figures for 1980 were 25 and 20. Most of the 1981 permits were for the coalfield area in the Plateau, but one well, being drilled by Atlantic Richfield Company, is going to basement at about 16,000 feet in the Valley and Ridge of Lee County. The well should traverse the Pine Mountain and Bales thrust sheets and will add much information on the structure of the rocks in the Ben Hur and Rose Hill oil fields.

Even the Blue Ridge and Piedmont provinces have a potential for oil and gas production on the basis of recently gathered data, which consists of seismic lines completed by the Consortium for Continental Reflection Profiling (Cook and others, 1979), the U. S. Geological Survey (Harris and Bayer, 1979), the Department of Energy, with the Tennessee Geological Survey (Milici and others, 1979), and others in the Appalachians of the U. S. and one drilling project in Quebec. There is compelling evidence that rocks belonging to the Blue Ridge and Piedmont provinces

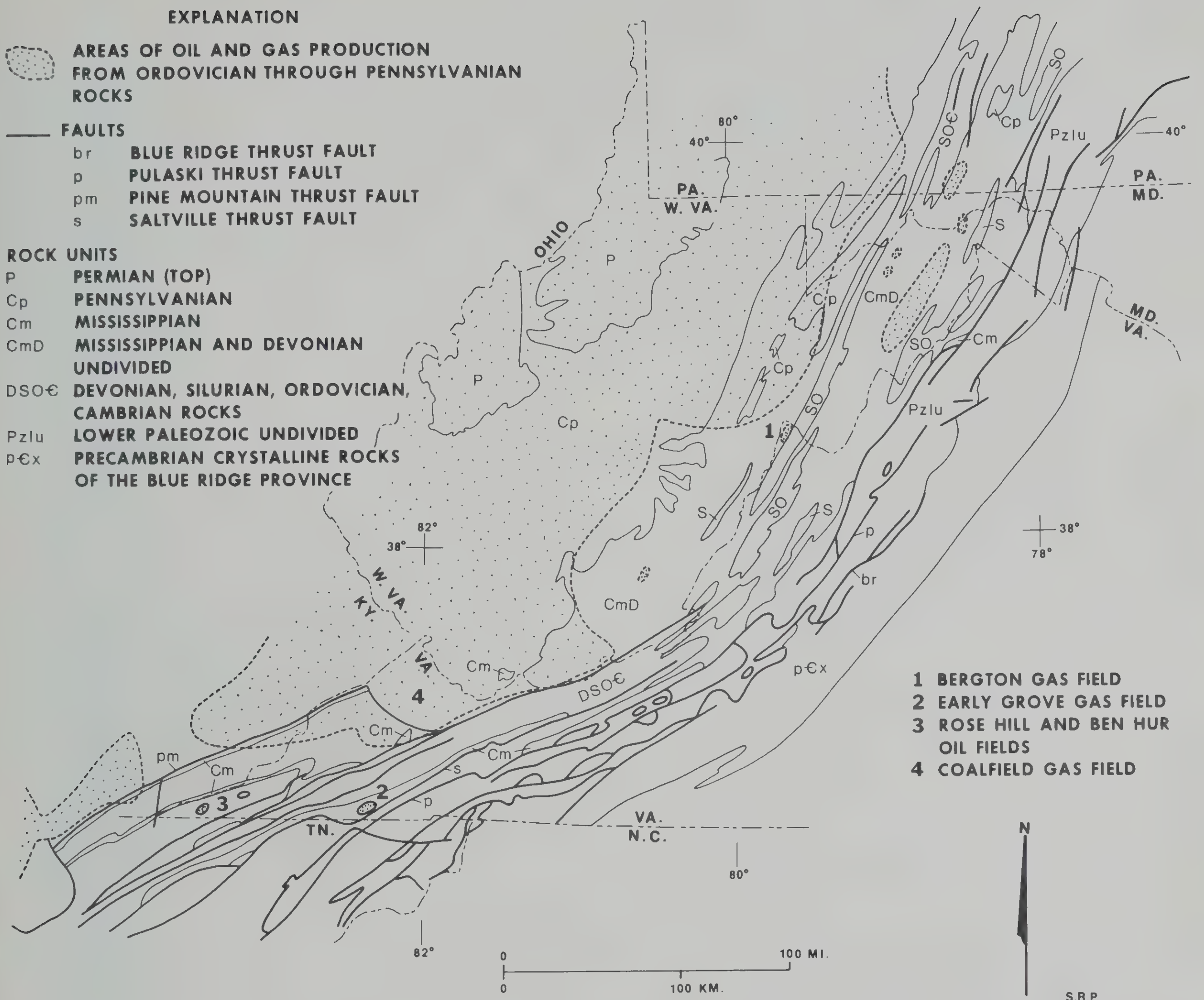

Figure 6. Generalized map of geology in part of the Eastern Overthrust Belt (after Milici, 1980). Most of the known gas and oil of the area lies west of Virginia. The great bulk of the gas produced in Virginia is from Lower Mississippian units, and areas where these rocks lie along thrust faults are good gas and oil prospects at depth on the fault footwall. At places on the figure, rock unit symbols are used in different combinations than is shown in the legend.

from Georgia to North Carolina and other eugeosynclinal rocks north to Quebec have been thrust over miogeosynclinal rocks of the Valley and Ridge province. Thus the Piedmont province constitutes a crystalline rock "veneer," in places from about 2.5 to 11 miles thick, overlying a much thinner section of chiefly Lower Paleozoic sedimentary rocks. The root zone of the thrust is not known, but the master decollement in the Southern Appalachians, and perhaps to the north as well, is interpreted by Harris and Bayer (1979) to extend from the continental shelf west through the Appalachian Plateau (Figure 3A). Seismic lines completed in June 1981 by the U. S. Geological Survey extend from Staunton to Norfolk along Interstate Highway 64 (line "B" in Figure 5). The line will provide abundant data on Valley and Ridge, Piedmont, and Coastal Plain structure and geologic history. Meanwhile leasing is active all along the foothills east of the Blue Ridge Mountains, as some oil companies prepare to drill in the area in an effort to find a strike in

the unmetamorphosed Paleozoic rocks lying beneath the Blue Ridge overthrust.

One region of the Virginia Piedmont is now being drilled for gas and oil, this is the Richmond Triassic basin in or near Chesterfield County (Figure 1). According to Dr. Bruce Goodwin, Consulting Geologist for Merrill Natural Resources, six holes have been drilled by the company a few miles west of Richmond in the basin. The wells have reportedly penetrated rocks with significant quantities of gas, a "good quality of oil," and several coal beds—one is eleven feet thick and three together total 20 feet. The gas is associated with the coal beds and with dark organic shales; the oil is in sandstones. Oil was known to be in these rocks as early as 1878 when it was observed seeping through outcrops of sandstone.Gas, like oil, was known to be in the rocks, because at times when the coal was being mined in about 1810, there had been methane explosions in the mines; in addition, a group called the Richmond Syndicate drilled seven wells in 1931 and reported "shows" of both oil and gas (G. Wilkes, personal communication, 1981).

If commercial quantities of gas are found in the Richmond Triassic basin, rapid exploitation is favored by the proximity of distribution lines leading to Richmond, reservoir depths of less than 2500 feet, and a gas flow that can probably be cheaply increased by hydrofracturing the rock down the well.

In addition to Merrill, at least two other oil companies and their leasing affiliates are in the area. One, Charles J. Maurer Oil Properties Inc., an exploration arm of Cornell Oil Company, is now drilling its third hole in the Richmond basin; its earliest drilled two wells are being evaluated by the Company. Merrill has a $78,000 grant from the Department of Energy under its Unconventional Energy Sources program to drill a deep well (2500 feet) near Salisbury, and the Company is awaiting arrival of a deep-drilling rig to finish one of its existing wells. Leasing activities are vigorous.

Excitement is mounting in Virginia as major oil companies, along with some minors, explore long forgotten potential in the Triassic basins and attempt to widen the fairway of the Eastern Overthrust Belt. Demand for hydrocarbons can only increase until the time these fuels are replaced by new energy sources. The tools for exploration are sharp enough for the task of finding the deeper fields in the complex structural areas that will provide much of the U. S.'s new reserves, and a year or two of drilling should do much to establish the onshore hydrocarbon potential for Virginia by determining if the gas and oil of the Plateau and western part of the Valley and Ridge are preserved in rocks of the same age farther east (Figure 6).

CONCLUSION

An enormous drilling effort is being conducted onshore in the U. S.; more than 9 million feet (1700 miles) were drilled in 1980 for exploration, development, stratigraphic and service wells, an eleven percent increase over the 1979 record-setting footage. The 1980 footage drilled in search of new fields was an all time record, and for dry holes it fell just short of the 1956 record. Most of the wells (a predicted 77 percent in 1981) were drilled by independent oil companies. In spite of these efforts, the U. S. production/reserve renewal ratio would be greater than one if it were not for revisions in estimates of reserves in *old* fields. New discoveries account for only about 29 percent of the amount of oil and gas needed to balance production (about 8.6 million barrels/day) against renewal*(Oil and Gas Journal,* 1981 C); the remainder of the balance (71 percent) is a matter of bookkeeping.

And even as this drilling effort continues, predicted energy needs are being revised sharply downward. A recent prediction of the needs for the year 2000 is only 99 quads, a figure substantially less than the 1978 prediction for 1980! These projections along with new discoveries in the U. S. and in Mexico and Canada are the most encouraging trends in energy supply that have come forth in a long while, though the downturn in use promises to choke off some of the federal and state tax revenue on oil, gasoline and natural gas, a wellspring that has been especially heavily counted on by the federal government. If new discoveries of oil and gas continue at the predicted rate, and if present conservation trends continue, the world should get through the year 2000, at least, without severe hardships arising as a consequence of oil and gas depletion (though there may be severe politically imposed shortages). Three factors threaten to reverse the conservation trend, however: loss of public concern (as indicated by a marked upturn in gasoline consumption in the late months of 1981), predicted decreases in real costs of oil, and possible government promotion of use.

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AUSTINVILLE MINE CLOSES

The New Jersey Zinc Company, a division of Gulf and Western Industries, Inc., ceased operation of their Austinville lead-zinc mine in Wythe County December 31, 1981. Having been active for 225 years, the Austinville mine was the oldest continuously operating mine in the United States and was the only active metal mine in Virginia. It employed approximately 200 persons and had an annual payroll of several million dollars before production was halted November 13, 1981.

An estimated 30 million tons of ore has been extracted from the mine workings which extend approximately six miles along strike and one-half mile across strike. An estimated 900,000 tons of reserves were on the books at the time of closing.

During operation 13,000 gallons of water per minute were pumped from the mine. As mining and pumping cease, an estimated billion gallons of ground water will flood the shafts and drifts. The flooding is expected to take about a year, and when full, the mine will contain enough water to produce a 265 acre lake, ten feet in depth. This underground water storage system has potential as a valuable reservoir in the future.

Lead from this mine was used to make ammunition for the firearms of pioneers, the Colonial Army, and the Confederacy and to cover the second roof of Virginia's Capitol in 1789-1790.

COAL RESOURCES STUDY

The Division has begun calculating coal resources for Lee, Wise, Dickenson, and Scott counties. This estimate of resources will be the newest resource data since the 1952 estimate by Brown and others. Resource calculations will be made with the cooperation of the U.S. Geological Survey who will calculate resources in Buchanan, Russell, and Tazewell counties.

Information on bed thickness, stratigraphic position and extent of mining has been collected during the past two years from a number of sources. These data have been entered into a computer data base and the resource calculations will be done on the computer. In addition to resource estimates, regional structural and stratigraphic studies will be possible using the computerized data base.

NEW PUBLICATION

Publication 33, — Analyses of Coal Samples Collected 1975-77 by Henderson, Oman, and Coleman, is available by mail for $4.62 from the Division.

Chemical analyses were performed by the U.S. Bureau of Mines and the U.S. Geological Survey. The U.S. Bureau of Mines analyses include proximate and ultimate analyses, forms of sulfur, heat value, fusibility of ash and the free swelling index.

The U.S. Geological Survey analyses include the major-, minor-, and trace-element concentrations in both ash and whole coal. Statistical tables contain arithmetic and geometric means, observed range, and the standard deviation for samples collected in Virginia and are compared with samples in the National Coal Resources Data System for Tennessee, Kentucky, and West Virginia.